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MR. JOS. M. WILSON, President, in the Chair.

THE ANAGLYPH: A NEW METHOD OF PRODUCING THE STEREOSCOPIC EFFECT.

BY MR. ALFRED F. WATCH.

The new stereoscopic pictures which I purpose showing you, and which are the invention of Mr. Ducos du Hauron, widely known from his valuable contributions to scientific photography, have, ever since their first appearance, created a great deal of interest and curiosity, and, by some, have been considered to involve the discovery of some new principle in photography. As they are printed in colors to produce the stereoscopic effect, they have been classed, by those not familiar with the manner in which they are made, among productions of chromo-photography, and it is the

object of this paper before the Institute to assign the anaglyph to its proper place among the recent discoveries, and to dispel any wrong impressions respecting these new pictures, which may have obtained currency through the publications of certain writers who have been misled by their appearance.

During the last decade, several eminent scientists and photographers have endeavored, in various ways, to produce stereoscopic pictures larger and different from the double ones, which are well known and which are viewed through a stereoscope; and some of these experimentalists—more enthusiastic than scientific—have even claimed that they could produce stereoscopic effects with prints from negatives taken from a single point of view. This claim, however, has not been proven to be correct, and doubtless never will be, as it would seem to be a physical and mathematical impossibility to realise it. The true visual stereoscopic effect can exist only where binocular vision exists. Therefore, to produce a stereoscopic effect, an object must be seen from two points of view at the same time, as is the case when those who have the use of both eyes look at an object. Each eye sees the same object from a different point, corresponding to its own position with reference to the other eye, and views it, in consequence, at a different angle. The two images on the two retinæ, blending or superimposing in the sense of vision, enable us, as the result of education and experience, to judge of the form of objects and of distances in perspectives. Therefore, to produce a stereoscopic effect in a flat picture, it is necessary so to compose it that it shall form the two distinct images which the objects depicted would produce in nature on the two retinæ of our eyes. No matter in what manner the pictures are brought before the vision, to produce stereoscopic effect two pictures are required. One of these pictures must represent the view of the right eye, and the other must represent the view of the left eye; and these two pictures, when viewed simultaneously and superimposed, produce the stereoscopic effect of binocular vision.

The "Anaglyphs," of which there are several specimens

here for your inspection, are not products of photography in colors, but simply a new kind of stereoscopic pictures, corresponding to the two images on our retinæ. They are printed, not side by side, as are the well-known stereoscopic pictures or photographs, but one over the other; thus making the prisms for their superimposition unnecessary, and making the function of the media through which they are viewed, simply that of separating the two images, and making each of them visible to that eye only, the vision of which it represents and depicts. At first thought, this would seem very difficult to do, and would seem to require very incomprehensible and complicated instruments; but when we know the principles on which the anaglyphic prints and apparatus are based, we shall find that the very simplest media—two pieces of differently colored glass—will solve the problem and reduce the blurred print into a perfect stereoscopic picture.

The whole anaglyphic process is based on two well-known facts, viz.: (1) If, through a transparent medium of some primary color, we look at an object of the same color, the object will appear almost colorless; and (2) if we look at the same object through a transparent medium of its complementary color, the object will appear almost black. By the combination of these two facts, Mr. du Hauron evolved the anaglyph.

The colors used have, for good reasons, been changed somewhat from the true complementary shades.

In the present anaglyphs, the picture corresponding to the view of the right eye is printed with *red* ink, and will appear almost black when seen through the *blue* glass, which will be in front of the right eye, when the "anaglyphoscope" is held before the eyes; but this *red* picture will be invisible to the left eye, which is covered by the *red* glass of the instrument. In like manner, the superimposed *blue* picture, which corresponds to the view of the left eye, will be visible to this eye only. Thus, each eye sees only one, its respective picture, and the two pictures, being superimposed in printing, require no prisms to produce the stereoscopic effect of binocular vision.

The instrument containing the media for looking at the these pictures (and which has been given the name "anaglyphoscope") consists principally of two pieces of plane glass of different colors, which may be mounted either in eye-glass or spectacle frames, or in boards with hoods, like the familiar stereoscopes. It makes no difference how the glasses are mounted, for, provided only that the colors are of the right quality and shade, the pictures can be seen as well through the eye-glasses, which can easily be carried, as through the hooded 'scope, although the latter possesses the advantage of shielding the eyes from extraneous light.

The anaglyphs, like the half-tones, are not entirely the products of photography, but require the aid and skill of the printer for their production; but the negatives from which the anaglyphs are produced, can be made by any amateur or professional photographer. To enable all to understand how these negatives and pictures are made, a short description of the *modus operandi* is herewith given.

As before stated, it requires two negatives to produce stereoscopic pictures. Heretofore all stereoscopic negatives and pictures have been limited to the size with which you are well acquainted, and which rarely exceeds $3\frac{1}{2}$ inches each in width, because the pictures are printed side by side, and the centers or corresponding points of the pictures could not be placed much further apart than the distance between the axes of the eyes of the observer.

In the anaglyphs, the two pictures are printed one almost on top of the other, which makes it possible, therefore, to produce stereoscopic pictures the size of the largest camera or enlargement. In making these negatives, the camera is mounted on a sliding base on the tripod-head, a specimen of which is here for your inspection. The camera is placed first at one end of the slide, from which point one exposure is made; then the camera is moved along the sliding base from 3 to 9 inches to the right or left, depending on the object, and another exposure is made of the same view from this second point, and on another plate. By giving equal exposures to both plates, a pair of matched stereoscopic plates is obtained, from which the half-tone plates are made

with which the anaglyphs are printed in colored inks on the typographic press.

As stated before, the pictures are printed one over the other, not exactly superimposed, or in register, but so that one print shall be a little to the right or left of the other, the lateral edges overlapping. The two impressions are printed far enough out of register to produce the desired stereoscopic effect, and near enough to avoid double vision.

Recently, anaglyphic lantern slides and transparencies have been perfected, but I regret that, at present, I am unprepared to show them.

In conclusion, I wish to mention that the anaglyphic process can be applied also to objects and articles which are not either direct or indirect results of photography. This process is applicable, for example, to painted, woven, and stenciled articles, such as ceilings, carpets, wall-papers, floors, etc.

This process was patented August 20th of the present year, and may, in the future, find useful applications in many of the arts and industries.

DISCUSSION.

Mr. John Carbutt asked if it were not necessary to make both negatives in the same horizontal line or plane?

Mr. Watch explained that inasmuch as our eyes usually are in the same horizontal plane, the negatives should be made so. There being no parallax in the vertical direction of the human vision, two negatives for stereoscopic pictures, made from two different points of elevation, or in two different horizontal planes, would produce in the pictures the effect of vertical strabismus.

Mr. Carbutt remarked that, in one or more of the pictures exhibited, the two prints seemed to be out of register vertically as well as horizontally.

Mr. Watch explained that this was due to the careless manner in which the half-tone plates had been trimmed.

SOME PREVENTABLE WASTES OF HEAT IN THE GENERATION AND USE OF STEAM.*

By William Kent, M.E.

"Waste makes want" and "saving of waste makes wealth" are two maxims which should be remembered by every user of coal. Nearly every one is interested in saving coal: the manufacturer, to save loss or to increase his profits; the consumer of manufactured goods, in the cheapening of their price; the nation at large, in the increase of wealth. Even the miner of coal may be interested in its saving, for no amount of possible saving of coal will equal in any one year the national increase of coal consumption due to increase of population and increase of national wealth. The more saving made, the more wealth grows, the more manufactured goods are wanted and the greater the demand for coal. So, the saving of coal does not throw the poor miner out of employment, or make less coal for the railroads to carry, or less to be handled by the teamsters or others who handle it after it leaves the railroads.

Waste of coal may begin in the coal pile itself, or in the handling of it, by its crushing into dust, which may be lost. Some varieties lose some of their heating power by the influence of the atmosphere—bituminous coal mainly—anthracite very little.

Wastes in the Boiler Furnace.—The principal waste of coal in its use for making steam begins in the furnace of the steam boiler, through improper styles of furnace, or improper methods of firing.

To treat of this element of waste properly, we must first consider what coal is, and how much heat-giving power it contains; and this leads us a short distance into the discussion of its chemical constitution.

If we submit a sample of coal to proximate chemical analysis, by heating it in a crucible, we find it consists of

* A lecture delivered before the Franklin Institute.

four constituents: (1) Moisture superficially contained among its particles, and which may be driven off by a heat of 212° F.; (2) volatile combustible matter, which may be distilled by heating to a red heat in a closed retort; (3) fixed carbon, which may be burned away by heating for a long time to a bright red heat in the presence of air; (4) ash, or the incombustible residue. Take two typical samples of American coal, good anthracite and Pittsburgh bituminous, and their composition when thus analysed may be expressed about as follows:

	Anthracite. Per Cent.	*Pittsburgh. Per Cent.*
Moisture	1	1
Volatile matter	5	33
Fixed carbon	84	60
Ash	10	6
	100	100

But we may analyse these coals by another method known as ultimate analysis; and in this case we will find their chemical constituents to be as follows:

	Anthracite. Per Cent.	*Pittsburgh. Per Cent.*
Moisture	1	1
Ash	10	6
Carbon, fixed	84	60
Carbon combined with hydrogen	3	18
Hydrogen combined with carbon	1	6
Hydrogen combined with oxygen	0·1	1
Oxygen combined with hydrogen	0·8	8
Nitrogen	0·1	—
	100·0	100

The moisture, ash, nitrogen, oxygen and that portion of the hydrogen which is chemically combined with oxygen, are incombustible, and consequently are of no value as heat-giving elements, leaving as the useful materials the carbon and the remainder of the hydrogen. From scientific experiments made by European authorities, we learn what amount of heat these combustible elements are capable of giving, as follows:

1 pound of carbon burned to carbonic acid (CO_2) . 14,500 heat units.
1 " " " oxide (CO) . 4,400 "

One pound of hydrogen burned to water, (H_2O), 62,000 heat units; a heat unit being defined as the amount of heat equivalent to that required to heat 1 pound of water from 39° F. to 40° F.; that is, 1 pound of carbon thoroughly burned gives off an amount of heat, which, if entirely absorbed by water, would heat 14,500 pounds 1°.

Knowing the heat-giving power of the elements, we can now calculate the amount of heat which our two samples of coal are capable of giving off, as follows:

Anthracite.		*Bituminous.*	
C ·87 × 14,500 =	11,615	·78 × 14,500 =	11,310
H ·01 × 62 000 =	620	·06 × 62,000 =	3,720
	12,235		15,030

This gives us a measure of how much heat we should expect to obtain by burning the coals, if we could burn them thoroughly and abstract all the heat generated. But the quantity in heat units may be translated into another kind of unit more generally understood. It is found, according to the experiments of Regnault and others, that 1 pound of water at 212°, evaporated into steam at the same temperature, absorbs 966 heat units, so that 1 pound of carbon with a heating power of 14,500 heat units is capable of giving off heat sufficient to evaporate, from 212°, into steam at the same temperature, $\frac{14,500}{966} = 15$ pounds of water. This is usually expressed by saying 1 pound of carbon can theoretically evaporate 15 pounds of water from and at 212°. In a steam boiler we usually feed the water into the boiler at some other temperature than 212°, and we always evaporate the water at some higher temperature; but knowing the number of pounds evaporated per pound of coal under actual conditions of feed-water temperature and steam pressure, we can calculate, by means of steam tables published in engineering reference books, what is the equivalent evaporation from and at 212°, and comparing this with the theoretical heating value of the combustible portion of the coal, we have what is known as the efficiency of the boiler, or the percentage of heat utilised by the boiler. The difference between this and 100 per cent. is the waste heat, some

of which may be preventable, and some not preventable. For instance, suppose we had a very pure anthracite, and the heating value of 1 pound of its combustible portion was equal to 14,500 heat units, which is equivalent to 15 pounds of water evaporated from and at 212°, and we had a steam boiler which gave, in actual trial, a result equivalent to the evaporation from and at 212°, of 12 pounds of water; then the efficiency of that boiler would be $\frac{12}{15} = 80$ per cent.

Such results have actually been obtained in steam boilers in tests with good anthracite coal. At the Centennial Exhibition in 1876, thirteen boilers were tested, which, when reduced to equivalent evaporation from and at 212° per pound of combustible, gave results as follows:

No. 1	12·094
2	11·988
3	11·923
4	11·906
5	11·822
6	11·583
7	11·039
8	10·930
9	10·834
10	10·618
11	10·312
12	10·041
13	10·021

It will be noticed that the first five boilers in the list gave a result very near 12 pounds. After the fifth boiler the results decrease rapidly down to the thirteenth, which gave a result of only 10·02 pounds, or 20 per cent. less than that of the highest boilers on the list. As all of these boilers were put in the best possible condition for test, were tested with good coal and by skilled firemen, and yet gave results differing by 20 per cent., it may well be realised that in ordinary practice, with average firemen, and, in many cases, badly proportioned and badly set boilers, as well as bad types of boilers, the difference between the best practice and the worst will be very much greater than 20 per cent.

Another record of actual boiler tests, showing what may be expected in average practice, is found in a book on boiler tests recently published by Mr. George H. Barrus, of Boston. Selecting from this book, the tests of which complete records are given, with different kinds of boilers, with different firemen, with different coal and in different parts of the country, we find the results of the tests as follows:

Water Evaporated per Pound Coal.	*Number of Tests Anthracite.*	*Number of Tests Semi-Bituminous.*	*Number of Tests Bituminous.*
Over 12 pounds	—	6	—
11·5 to 12 pounds	2	6	—
11 to 11·15 pounds	10	5	—
10·5 to 11 pounds	20	3	—
10 to 10·5 pounds	11	5	1
9 to 10 pounds	14	6	2
8 to 9 pounds	8	3	—
6 to 7 pounds	1	—	—
	64	34	3

Out of sixty-four tests with anthracite coal, only two gave a result over 11·5 pounds, and, as shown in the Centennial tests, a result of 11·5 pounds was obtained with five different types of boilers, and it may be obtained with any boiler properly designed and set, fired with good coal and with a good fireman. Twenty-three out of the 64 boilers gave a result below 10 pounds, or 20 per cent. less than the highest economy attainable. In the semi-bituminous tests, only 6 boilers out of 34 gave a result of 12 pounds, which figure is not difficult to obtain with this coal in any good form of boiler properly proportioned, properly set and properly fired. From these figures, the enormous waste of coal that is continually going on in the United States in steam boiler practice, may be appreciated.

Let us now consider the causes of this waste. First, is the waste due to improper burning of the coal? In burning anthracite coal, we may have too deep a bed of coal for the amount of draught obtainable, or too little draught for the thickness of coal on the bed; and in both of these cases we will have imperfect combustion of the coal, burning a portion of the carbon to CO instead of CO_2, and obtaining from it only 4,400 heat units per pound, instead of 14,500.

This is an easily preventable waste, for this condition does not obtain to any extent if the relations of thickness of bed and of draught are such as to make the fire very hot and bright. If the fire is dull and sluggish, imperfect combustion may be suspected.

A second cause of waste is exactly the opposite of the first, namely, too much draught for the thickness of bed, or too thin a bed for the amount of draught. In Professor Johnson's report of tests made for the United States Navy, in 1844, he gives results of various tests of anthracite coal, from which we learn that the Lehigh Coal and Navigation Company's coal is by far the worst of all the anthracites. Studying closely the record of this test, we find that the reason why this coal gave such a bad result was solely because too much air was allowed to pass through the fire, and the analysis of the chimney gases showed that twice as much air,was passing through the fire as is customary in the best practice. If Professor Johnson had caused still more air to pass through the fire, no doubt he would have put out the fire altogether by chilling the coal with cold air. But if, on the contrary, he had made his bed of coal on the grate twice as thick, he would have restricted the excess of air, and might have obtained the maximum result from that coal, instead of the minimum.

These two causes of waste—imperfect combustion through deficiency of air supply, and chilling the fire by excessive air supply—are usually both within the control of the fireman. No specific directions can be given which will apply in each case, and each boiler owner should, for himself, determine the best conditions of thickness of bed, method of firing, etc., which will apply in his own particular case, and make his rules of firing from his own experience.

In burning bituminous coal we meet real difficulties. As shown in our proximate analysis, by heating the coal to a dull-red heat, we drive off volatile combustible gases. In actual boiler practice, the furnace in the boiler in this way becomes a gas producer, and if the gases are driven off rapidly and at a low temperature, they are chilled by the comparatively cold surfaces of the boiler, and pass off into

the chimney unburned. In the semi-bituminous coals the waste due to this unburned gas is not so very great, since the total amount of volatile matter in the coal is usually not as much as 20 per cent. of its weight, and such volatile matter as there is in it is distilled rather slowly, and it gets a chance to burn before leaving the furnace. In all coals mined west of the Alleghenies, however, constituting the truly bituminous coals—and which are far greater in quantity than the anthracite and the semi-bituminous taken together—the volatile gases are much larger in quantity and are distilled rapidly at a low temperature, and it has not yet been found possible in average practice to prevent the escape of a large portion of these gases, with their accompanying smoke. The pall of smoke which rests over all our cities in the West is a monument to our bad engineering in not having found a way to practically utilise these gases, which are thus sent to waste. In ordinary boiler practice, with boilers as now set, all of this waste is not preventable; but that it is entirely preventable with different setting of boilers is clearly shown by the experience in steel-melting furnaces, in which the gas is first distilled in a chamber known as a gas producer, and is then carried through hot chambers of fire-brick, and heated to a high temperature, and burned with a sufficient supply of air, which has also been pre-heated by passing through similar hot chambers. With this apparatus, the gases are thoroughly burned and no smoke whatever is made. The only thing which prevents this furnace being applied to a steam boiler is the cost of construction and of maintenance. It is, however, entirely feasible, with a much simpler apparatus, to save very much of the waste gas, and prevent much of the smoke. This apparatus consists simply of a large fire-brick oven, built in front of the boiler, which serves both as a gas producer and as a combustion chamber. The conditions necessary for burning bituminous coal properly are that the gas should be heated, and that the air used to burn it should also be heated; that the combustion be carried on in intensely hot chambers; and that time enough be given for the gases and air to thoroughly intermingle before they are allowed to escape.

These conditions can be provided in a properly built oven with air-heating flues in it, but they cannot be provided in the ordinary boiler setting, because the latter does not give sufficient room.

Wastes in the Boiler Itself.—The next direction in which waste may be found in steam boilers is in the boiler itself. If it has an insufficient extent of heating surface, the gases, although properly burned in the furnace, may be allowed to pass into the chimney too hot. In ordinary stationary practice, a good rule for proportioning the heating surface is to allow 1 square foot of surface for every 3 pounds of water required to be evaporated per hour. Fifty per cent. more than this will do no harm, and may be useful in emergencies; but if less is given, excessive waste of heat in the chimney may be expected.

Another cause of waste is that, with sufficient extent of heating surface, this surface may be so placed as not to be efficient; that is, the gases may be allowed to be short-circuited, or take short passages from the furnace to the chimney, without passing uniformly over the whole extent of the heating surface. I have found this trouble in ordinary tubular boilers, in which the hot gases, after passing under the boiler, had a tendency to return through the upper rows of tubes and neglect the lower rows. In consequence, the latter were rendered ineffective, and the gases passed into the chimney at a higher temperature than if they had been compelled to sweep uniformly over the whole extent of heating surface.

Another cause of waste is the unclean condition of the boiler inside, or outside, or both. Scale on the water side of the heating surface of a boiler, and soot on the opposite side, are both non-conductors of heat, and their presence leads to waste.

The indications of waste in steam boilers are very plain; first, if the conditions of firing, draught, thickness of bed, etc., are right, there will be a very high temperature in the furnace. If there is a low temperature, either from imperfect combustion or from too great amount of air, there will be a waste, so that high temperature in the furnace is the

first condition of economy in a steam boiler. The second prime condition is low temperature in the chimney. The heat produced in the furnace must be absorbed as completely as possible by plenty of heating surface, and by clean heating surface, and by surface properly disposed so as to intercept the currents of gas, and the result will be a low temperature in the chimney. Smoke is also an indication of waste, and wherever smoke is seen, there also will be unburned combustible gases, which, as before stated, may be prevented.

Other causes of waste in steam boilers may, however, exist, coincidently with a low temperature in the chimney. One of these may be due to the passage of cold air through the rear portion of the furnace, which the fireman is very apt to leave uncovered. Another may be due to leaks of air through the setting of the boiler. This cold air absorbs heat from the furnace and boiler, and carries heat into the chimney. A third may be due to leaks of water into the furnace or flues, which abstracts heat by its evaporation, and passes into the chimney as superheated steam. Still another cause of waste, quite frequently found, is a leaky blow-off valve, as where the valve discharges into a sewer, and its leaky condition is not observed. Another cause of waste in a steam boiler, which is found in some establishments, is the waste of steam through the safety valve. In some places, where the demand for steam is irregular, but which when needed must be at a certain pressure, and the boilers are not safe to be carried at much higher pressure, the safety valves must be set at very little above the working pressure. When the work ceases for a short time steam accumulates in the boiler, and is blown off in the safety valve. The remedy for this kind of loss is to have stronger boilers, in which the pressure can be allowed to accumulate to a considerable point above the working pressure, and boilers with a large area of water level, which will allow the pumping into the boiler of a large quantity of water to absorb the excess of heat when the demand for steam is diminished, and give it out when the demand is increased. In all places where the demand for steam is irregular, great attention

should be paid to the regulation of the damper, so as to prevent fuel being wasted when the demand for steam is small. Another cause of waste in a steam boiler is too small a grate surface, causing the grates to be easily choked with clinker, and requiring more work of the fireman to keep them clean. Every time the fire is cleaned there is a waste caused by cold air rushing in the doors, and by unburned fuel being withdrawn with the clinker.

Waste Heat in the Chimney.—With a properly set boiler, running to its normal capacity, it is not usually practicable to reduce the temperature of the flue to less than 100° in excess of the temperature of the steam in the boiler, or, say, to 400° or 450°. In actual practice, 500° is more common than 400°, and in bad practice I have observed over 1,000°. But, if 400° is the lowest we can get, and the temperature of the air entering the boiler room is 80°, the hot gases leave the boiler 320° higher than the temperature of the entering air. As the temperature of the fire is not usually much above 2,000°, say, 2,400° as a maximum, the heat thus lost in the chimney is from 13 to 16 per cent. of the total heat generated by the coal. This loss is unavoidable with an ordinary boiler and chimney: first, because a moderately high temperature is necessary to make a good draught; and, second, as already stated, because we cannot reduce the temperature of the gases down to the temperature of the steam. But much of it may be saved by the use of an economiser, or set of tubes placed in the chimney, through which the feed water is passed, and heated from the entering temperature to nearly, or quite, that of the boiler. In large plants, considerable economy of heat may be had by use of these economisers, using either a very high chimney, or, better, forced draught, either blowing air in under the grate, or exhausting it out after it passes the economiser.

Wastes in Steam Piping.—We will now consider briefly some of the wastes in the use of steam, supposing that we have prevented all the wastes that we can in the steam boiler. The first waste in the use of steam is due to radiation of heat from the steam pipes. I copy the following from a published table, showing how much horse-power

may be lost from uncovered steam pipes, with the steam at 75 pounds gauge pressure:

2-inch	pipe,	1	horse-power	lost	for	every	132	feet	long.
4	"	"	1	"	"	"	"	75	"	
6	"	"	1	"	"	"	"	46	"	
8	"	"	1	"	"	"	"	40	"	
12	"	"	1	"	"	"	"	26	"	

About 90 per cent. of this waste is easily prevented by a proper covering of the pipes.

Leaks of steam from the joints and valves in steam pipes are a frequent and entirely inexcusable source of waste. Another cause of waste of the power of steam is caused by the pipes being too small and elbows too numerous, causing a serious reduction of pressure between the boiler and engine. Economising in the first cost of steam pipes and of coverings generally leads to a continual waste of heat and power.

Wastes in the Engine.—In the steam engine itself the wastes are numerous. First, there is that due to condensation of the steam as it enters the cylinder. This may cause a waste of anywhere from 10 to 50 per cent., or even more, of the whole amount of steam used. Second, there is the waste of steam in engines which are overloaded, due to exhausting the steam at too high a terminal pressure. Third, there is the waste of steam in high-pressure engines which are not loaded heavily enough, by exhausting the steam below atmospheric pressure, and requiring the engine itself to do the useless work of pushing the piston against a pressure equal to the difference between the atmospheric pressure and that of the partial vacuum behind the piston. This cause of waste becomes a very serious one in the high-pressure, non-condensing compound engine, unless special devices, such as regulation of the compression, are used to avoid it. The last two named sources of waste can be reduced to a minimum only by properly proportioning the engine to the work to be done. If the engine is to be run at a uniform load, the expansion of steam should be carried in it to such a point that the steam, when exhausted, will be at or near the back pressure in the cylinder.

Cylinder condensation has never been entirely prevented; but, as we know its causes, we can modify them to a great extent. Too short cut-off underneath involves, in high-pressure engines, expanding below the atmosphere, but also increased cylinder condensation. In high-pressure engines, therefore, we find that the maximum economy is obtained in single cylinder engines when the cut-off is between one-quarter and one-fifth of the stroke. Earlier cut-offs and later cut-offs both give worse economy. If we wish to economise steam still more than we can do in the single cylinder engine, we must use a compound engine, and, to get the maximum economy obtainable with present practice, we must expand the steam in three cylinders, beginning with steam of about 160 pounds pressure or upwards, and expanding from sixteen to twenty times.

The range of wastes in the steam engine may be understood from the following table, showing what may be expected to be the water consumed per horse-power per hour in different types of engine:

Common direct-acting pump	100	pounds	and upwards.
Old style slow-speed throttling engine, non-condensing	45	"	"
Modern high-speed automatic cut-off . . .	30	"	"
Compound " " " . .	22	"	"
Corliss single cylinder high-pressure . . .	20	"	"
" " " condensing	18	"	"
" compound "	14	"	"
" triple-expansion condensing	12½	"	"

These figures represent about the best practice of the several types, and the word "upwards" represents any indefinitely greater amount which may be due to bad proportioning, bad setting of valves, leaks, or other causes. They show that the best triple-expansion engine will use only one-eighth of the amount of steam used by one of the worst types of engine, and less than half of the steam that is used by what is considered to be a first-class engine in ordinary stationary practice. All the consumption of steam in excess of 12½ pounds per hour per horse-power may be considered to be a preventable waste; but, as triple-expansion and compound engines are very expensive, the

interest on their cost and the increased cost of their maintenance may, in certain conditions and in certain localities, be greater than the saving in fuel. Generally, it will pay to put in a triple-expansion engine in all cases where the power required is over 500 horse-power, and the time of maximum service is more than ten hours a day. For smaller horse-powers, and for time of maximum load less than ten hours a day, it will, generally, not pay to use so expensive an engine.

Efficiency of the Steam Engine.—If we take the engine which uses only 12½ pounds of water per horse-power per hour, and estimate that for every pound of water taken into the boiler, there is added to it 1,100 units of heat to convert it into steam of the desired pressure, this gives 13,750 heat units required per indicated horse-power per hour. As a horse-power per hour equals 1,980,000 foot-pounds of work, this, divided by 772, the mechanical equivalent of heat, gives only 2,569 heat units per hour, which, theoretically, are required to produce one horse-power. We have, therefore, as the efficiency of this engine, in relation to the heat in the steam used, $\frac{2569}{13750} = 18{\cdot}68$ per cent. If we have a boiler which gives 75 per cent. efficiency, then the combined efficiency of the boiler and engine is $18{\cdot}68 \times {\cdot}75 = 14{\cdot}01$ per cent. So that, in the best modern type of engine, we obtain only one-seventh of the heating value of the coal used; the other six-sevenths are absolute waste; but as far as our present knowledge extends, they are non-preventable. There does not seem to be any possibility of greatly reducing the waste in the steam engine, so that its consumption will be less than 12½ pounds per hour. In all steam engines we must throw away either hot steam, as in high-pressure engines, or a vast volume of hot water, as in non-condensing engines; and in the latter case there is no known way of recovering the heat from the water that we throw away, so as to use it again in the engine. It may be left for the next century to discover some way of obtaining mechanical energy from coal without the intervention of the steam engine, but at present there seems to be no prospect

of such an invention. The preventable wastes, however, are those enormous wastes which are indicated by the difference between a consumption of 12½ pounds per hour per horse-power, and the 25, 35, or even 100 pounds which are used in the various types of engines, and the still more inexcusable wastes which are indicated by the difference in the figures showing the best practice and the worst in steam boilers.

TECHNICAL NOTES ON THE GRAMOPHONE.*

By Emile Berliner.

Professor Houston introduced the lecturer, who spoke as follows:

Members of the Institute, Ladies and Gentlemen:

It is the purpose of this paper to lay before you some recent experiences gathered during my work on the gramophone. It may enable future experimenters, in the field of recording and reproducing sounds, to avoid many perplexities, and at once to start into new paths of investigation, without the necessity of becoming initiated, by tedious research of their own, into the A, B, C of this new art.

Gramophony may be divided into eight principal sections: (1) The recording sound-box; (2) zinc; (3) cleaning and coating; (4) sound collectors; (5) etching; (6) the reproducing sound-box; (7) duplicating processes; (8) general features.

The Recording Sound-Box (*Figs. 1, 2* and *3*).—The diaphragm, *A*, is of mica, $\frac{5}{1000}$ inch thick, and has a free vibrating surface of 1¾ inches. A ring of blotting-paper is laid on its periphery, between the clamping surfaces of the brass sound-box, *B*. The short brass tube, *C*, to which the sound collectors are attached, is about 1⅛ inches long, with a bore $\frac{11}{16}$ inch in diameter. At the inner end of this

* This paper is an elaboration of the system of gramophony, as described by Mr. Berliner, in a previous paper read by him before the Franklin Institute, and published in the *Journal*, **125**, 425.

tube a perforated cork, *D*, is inserted. This cork seems to act as a perforated diaphragm similar to the diaphragms in optical instruments, meaning thereby, that it cuts off some interfering elements of the vibrations, without impairing the strength of the effects to be attained. To the center of the mica diaphragm is fastened a thin block of hard rubber, *F*, covered with soft rubber, and a damping-spring, *G*, presses against the block, and is attached to it with wax. The free end of this spring is bent upwards. The stylus, *R*, is of steel, $\frac{2}{1000}$ inch thick, with a maximum width of $\frac{3}{8}$ inch, and its free elastic end is $\frac{1}{2}$ inch long. It is tipped with osmium-iridium, *H*, of moderately hard quality. The

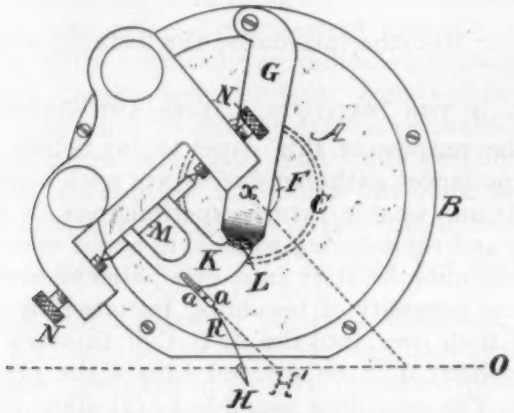

FIG. 1.

iridium is first welded to a small blade of gold, *J*, and this is soldered to the steel stylus. The iridium point is next ground down, on a fine emery wheel, to a nice point, representing a pyramid cut in two from apex to base, and dividing the base into two rectangular halves. The steel blade is inserted and soldered into the holder, *K*, of thin sheet metal, which should be as light as possible without impairing its stability, and is shaped in such a manner that the distance from the displaced center of the diaphragm to the iridium point is reduced to a practical minimum. The holder is connected to the damping spring by a mixture of shoemaker's wax and beeswax, *L*, soft or hard, according to

the season of the year. I found this method of fastening better than the finest mechanical or elastic connecting device, and it permits of easy disconnection, by a lighted match held to the wax joint, whenever it is found necessary to examine either the iridium point or the pivot, *M*. The latter is represented by a steel pin, whose hardened points are held between two adjustable screws, *N*, *N*. The adjustment must not be so loose that the stylus can fall by its own weight.

It will be seen that if, as shown in *Fig. 1*, a stylus be laid diagonally, in the writing position, across the center of a

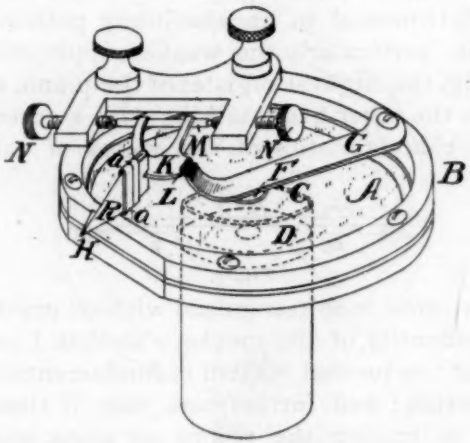

FIG. 2.

diaphragm of the same size as that used, the distance from center of diaphragm, *X*, to iridium tip, if the latter stands, say, $\frac{1}{16}$ inch over the base line, *O*, representing the zinc surface, would be about $1\frac{3}{8}$ inches; while in the present construction, in which the extended point of the damping spring is supposed to move almost parallel with the center of the diaphragm, the virtual distance, namely, that from *L* to *H*, is only $\frac{3}{4}$ inch.

The steel blade is bent downwards about $\frac{1}{4}$ inch below the working line, *i. e.*, the zinc surface, and it is straightened out when set for recording.

By modifying either of the elements of the system, some

effects become superior at the expense of others, which, of course, would have to be considered as faulty.

The wonderful mechanism of the human ear, which makes it possible for us to take notice of the scratch of a pen 10 feet away, and at the same time enables us to correctly analyse, at close proximity, the compound effects of a whole brass band, forms an ideal mechanical system, which, however, baffles all mechanical laws if we were to try to appreciate the meaning of all its internal working parts.

Speaking critically, I am aware that the resistance in the leverage in the present recording stylus, and also the friction of the iridium point against the zinc, are elements somewhat detrimental to an absolutely perfect recording of all sounds, particularly the weaker upper vibrations of low whistling, the highest register of the piano, and similar sounds. On the other hand, talking with a foreign dialect and all the characteristics of the voices of various indi-

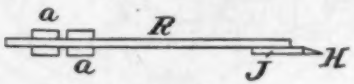

FIG. 3.

viduals, have often been recognised without previous knowledge of the identity of the speaker; so that I am inclined to assert that the present system is fundamental in its general construction; and furthermore, that if time be taken to go back to tracing the record on glass, and to photo-engrave the same, the effects would represent the highest state of perfection and a uniform one for all sounds.

An almost perfectly working diaphragm, I have found to consist of stretched soft leather, pulled out at the center in the manner of the tympanum of the human ear; but it was inconstant in action, because the stretching would slacken it, and the substitution of soft rubber for the leather proved to be too elastic.

In soldering the iridium-tipped gold piece to the steel blade, great care must be taken not to draw the temper of the latter. When German-silver was used instead of the gold, the iridium tip was invariably too hard, and would scratch into the zinc. The reason of this I have, at one time, sup-

posed to be the difference of temperature employed for welding the iridium to the various metals, but it may have been due to the iridium itself. I have experimented with small diamond points, but they invariably scratch the zinc surface, even when the pressure of the steel blade, which generally is about 5 grams, was reduced. Tips of softer iridium, or of hardened steel, would not take hold of the zinc for any length of time with sufficient distinctness, and the result would be a rougher etching. Speaking generally, the tracing point should burnish the zinc, but not scratch it.

The present semi-hard iridium point must occasionally

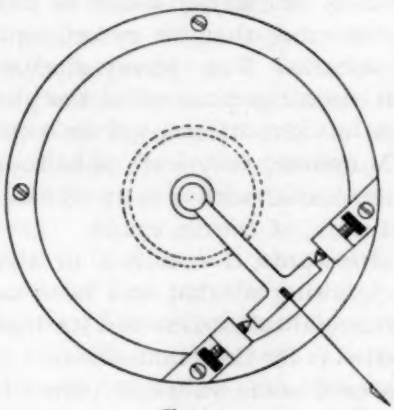

FIG. 4.

be touched up on a fine emery wheel. If glass or hard steel is employed as a register surface, a small diamond point would probably be a model tracing tip, although it might be found that the loading necessary for attaching it to the steel blade, at this, its most sensitive, point, might prove detrimental to its mechanical functions.

The steel blade is damped by two narrow, soft rubber rings, *a* and *a*, which are slipped over it as high up as possible.*

In giving these end results, some idea may be formed of

* The system of mounting the stylus as shown in *Fig. 4* was repeatedly tried, but thus far the results have not been as good as one might expect from it.

the mass of experiments, most of them quite empirical, which were necessary for drawing the final conclusions with reference solely to the construction of the recording sound-box. Altering a single element, or proportion of parts, will somewhat modify the results, and the avoidance of errors in personal equation, as to the results obtained, has not been the least important part of the experiments. Fortunately, the field is most interesting, and the spirit of investigation is readily kept up, even after most trying interferences of unknown sources of error in the combined sections with which this paper deals.

Zinc.—Those of you who were present when I first brought the process of etching sound to public notice in this hall, will remember that, for recording-tablets, heavy discs of pure, so-called New Jersey zinc were used. I followed, at that time, the practice of the photo-engravers, and the expense of zinc discs used in experiments was considerable. Moreover, they were only roughly polished and were heavily coated with a fatty etching-ground; the results obtained were, of course, crude.

Some time afterwards, I resolved to strike out independently, and, ignoring all that had been said about impurities in commercial rolled zinc and its inadaptability to fine etching, I tried it for the gramophone.

I soon discovered some valuable points of superiority, which the common zinc had over the so-called pure zinc. It was harder, very much cheaper, could be used in much thinner discs, took a very high polish, etched more readily, retained its flatness better—being somewhat elastic—and proved itself to be in no points inferior to the pure zinc, while it resisted better the wear of the reproducing stylus.

Of course, it is advantageous to use only good Belgium, Silesian, or Illinois zinc, and it should receive the highest attainable polish.

After being polished, the discs are roughly cleaned in benzine on both sides and around the edges, and are then piled up accurately and subjected to pressure for about thirty-six hours in an ordinary letter-press, after which they will be found perfectly flat and ready for a final cleaning.

The discs have in the center a hole of the standard diameter of 7 millimeters, or $\frac{9}{32}$ inch.

Cleaning and Coating.—The disc is laid on a clean, flat and even slab, having in the center a low pin for holding the center hole. Pieces of very soft white cotton cloth (but not Canton flannel), about 2 inches square, are cut in sufficient quantities, and good benzine, gasoline, or, better yet, petroleum ether (if obtainable), is dripped on the polished face and a piece of cotton rubbed quickly and firmly over it. The rubbing is done principally in quick and short circles around the periphery of the disc. After repeating this several times and always with a fresh or turned piece of cotton, it will be found that at last the finger marks on the cotton appear, but as slight dark markings. If the zinc should accidently be softer and more easily abraded, the benzine circles under the moving fingers will quickly disappear without showing any traces, and either sign is a proof that the disc is ready for coating. This should be done at once, and the polished face should never be touched with the fingers.

Coating ought to be done in a warm and dry room, and the solution used for that purpose (which is the same fatty extract of beeswax as described in my paper before this Institute, of May 16, 1888), must be kept in a moderately warm atmosphere. In addition to this, the disc, having been fixed on a holder pushed through the center hole, is warmed over a flame, so as to appear very slightly warmer than the hand when held against the back of the disc.

The fatty extract is now poured on and off, and the last drippings are removed with a piece of cloth, while the disc is quickly dried with the breath or a handy fan. The fatty coating should then appear as a perfectly uniform, dull-looking surface, showing no bright lines or patches which would likely be subsequently etched through. The fatty film may be so thin as to appear somewhat iridescent, but not over much so, nor should it appear so dense as to be likely to offer too great a resistance to the stylus point. The coated discs may be preserved, so far as I have been able to judge, for an indefinite time, but they should be kept free from dust or handling.

Sound Collectors.—In acoustic science, the most efficient sound collectors, so far as mere loudness is concerned, are conical in shape and are of hard material. They are generally individual resonators, meaning thereby, that they enclose a column of air representing a tone of a certain pitch, which tone, when produced in close proximity thereto, will be reinforced by said air column. Hence, the smaller the column of air and the higher its pitch, the less will its reverberating, or reinforcing, effects be noticeable with ordinary sound phenomena. Furthermore, if the sides of the sound collector are of yielding, but not very elastic material, or if they are slightly perforated at many points, the individual resonance is proportionately weakened. The outer ear is both small and of yielding material, and, in a healthy state, is a sound collector neutral to all the sounds appreciable by the inner ear. It does not reinforce them, but acts as a collector and conveyor of sound, pure and simple. The column of air enclosed in a violin would resonate and reinforce its fundamental tone, were it not that the material of which a violin is made is elastic or yielding and eliminates the individual resonance.

The first telephones had large sound chambers and produced interfering sounds due to individual resonants. The harder and more unyielding the material of which a resonator is made, the more intense the reverberation of its fundamental tone; hence, the intensity of the sounds of organ-pipes, trumpets and whistles, with the application of even small air pressure.

In telephones and transmitters in which the mechanical work is infinitesimal, only small sound collectors are required, and, after a first few mistakes in telephony, no trouble was experienced in constructing them.

Not so with loud-talking machines, in which the voice is expected to do considerable mechanical work. Its whole energy, if possible, must be collected and brought to bear on the diaphragm, and this with as little inconvenience as possible to the speaker or singer.

Of all sound collectors, ordinary flexible speaking tubes, conical in extent, which, as I have found, ought to be

slightly perforated, so as to destroy the individual resonance, have been found most efficient and convenient for speaking and singing.

For instrumental music, medium-sized, but perforated funnels, of metal or hard pasteboard, *Fig. 5*, are very serviceable. For the piano, an arrangement, such as shown in *Fig. 6*, is employed. For voice and piano, or cornet and piano, a coupling, *Fig. 7*, is used. For clarionet and piano, also for band music, the arrangement shown in *Fig. 5* holds its own.

These are the principal types of sound collectors at pres-

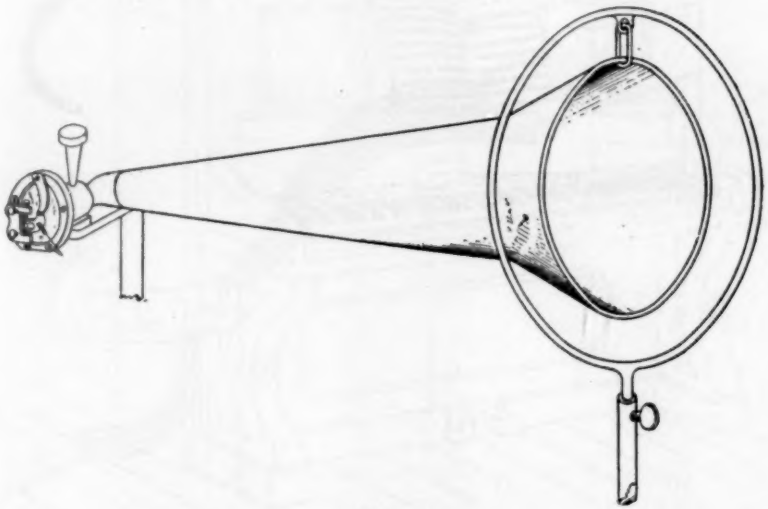

FIG. 5.

ent used by me; but experimentally, a large variety was tried, and would form quite a collection.

Etching.—Up to a short time ago, I used, for this purpose, commercial chromic acid, that is, the dry powder as found in the market, dissolved in water so as to form a solution of a deep wine-red color.

Lately, however, I use a liquid prepared by adding to a concentrated solution of bichromate of potash, sufficient sulphuric acid to just prevent the formation of hydrogen bubbles when dropped on zinc. This solution, I find, is

superior to the commercial chromic acid, and is very much cheaper.

In summer, the etching fluid must be kept in an ice-box, and the etching tray should be placed in a cold water bath, because considerable heat is produced during etching, and, added to that, a warm outer temperature would soften the fatty film and expose the metal to the action of the acid.

The duration of the etching process should be governed by the average amplitude of the record waves as viewed

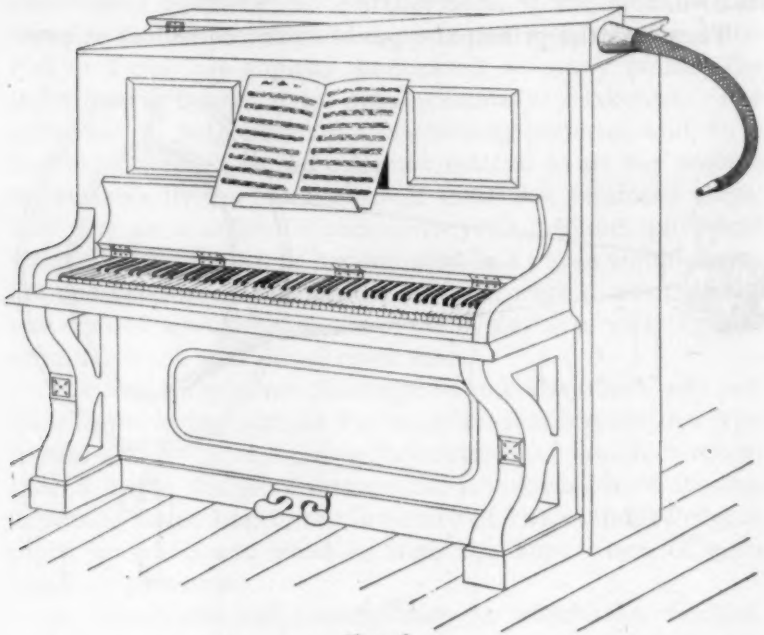

FIG. 6.

through a magnifying glass, and should be as short as possible. For ordinary conversation, and in a warm room, ten minutes is generally sufficient; for loud band effects, about twenty minutes are required. The grooves must be etched just wide enough to permit a well-pointed reproducing stylus to travel freely through the wave lines; but, if etched records are to be printed or transferred, the duration of etching must be shorter. Sound etchings on glass have been only partially successful, because the etching

ground would not withstand an acid of sufficient strength so as to make a sharp and perpendicular etching.

Etching by electricity has also been tried. The difficulty in this method was found in the electrostatic condition of the etching ground between the metal and the electrolytic fluid, which would apparently disturb its function of keeping the acid from attacking the metal.

An odd effect is produced by etching ink records with acetate of lead. The lead bushes will gradually cover the whole record ring, without, however, interfering with the etching ground underneath.

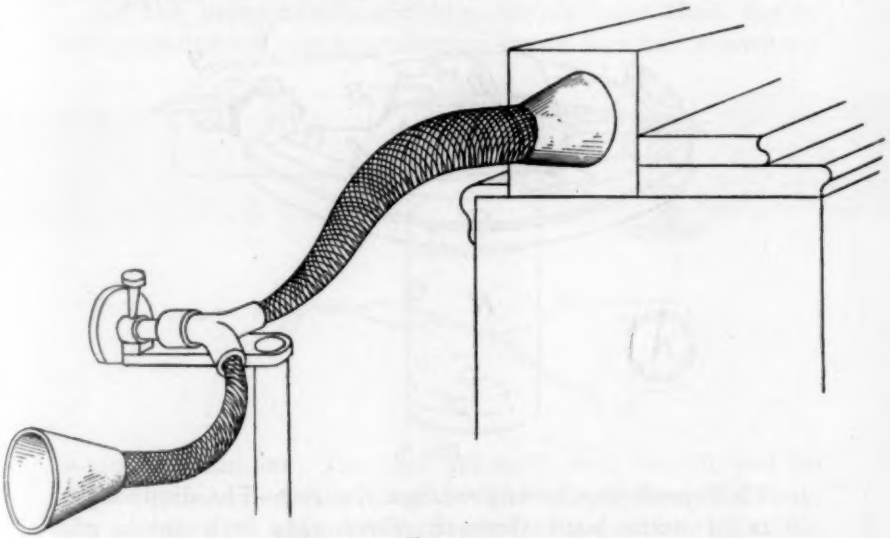

FIG. 7.

Etching has been done on hard rubber, celluloid, and the principal base metals, but zinc offers advantages over all these, and is not likely to be superseded. Polished steel would perhaps be the metal *par excellence*, but it is expensive and must be reserved for a future and more advanced state of the art.

As a side issue to gramophonic etching, a fact, important to metal-workers, was brought out in my laboratory. It was found that a solution of commercial chromic acid is the very best means for cleaning brass or copper objects.

When immersed, for from ten to thirty seconds, in such a solution, they acquire that beautiful pure surface found only in fresh electrolytic deposits. During the past year the United States Patent Office had a force of mechanics at work preparing and fixing up old models for the Columbian Fair exhibit. At a suggestion of a former assistant of mine, the office adopted the plan of cleaning with chromic acid. Entire models, often very valuable from their fine workmanship, were dipped in the solution and then washed in water and lye. The acid does not attack iron or steel, and therefore the finest bearings did not suffer.

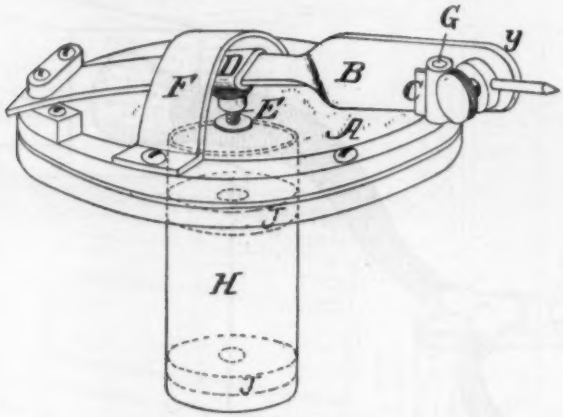

FIG. 8.

The Reproducing Sound-Box (*Figs. 8, 9, 10.*)—The diaphragm, *A*, is of extra hard German silver, $\frac{1}{100}$ inch thick, and has a free vibrating surface of $1\frac{5}{8}$ inches. The spring stylus, *B*, which passes across the center of the diaphragm, is firmly fixed to the diaphragm box on the upper edge, and the other free end, which presses against the opposite or lower side of the diaphragm box, has just sufficient elasticity to vibrate under the impact of the etched sound vibrations.

This spring stylus has been evolved from a large number of experiments, and is both compact and efficient. It is originally, as shown in *Figs. 9* and *10*, a flat steel blade, $\frac{7}{16}$ inch wide and $\frac{1}{40}$ inch thick. It is first softened, twisted

at right angles, curved, and then again hardened, after which a blue temper is drawn in oil. In spite of its stiffness and compactness, it is a delicate part of the gramophone, and very much depends on its correct condition.

To make a first-class reproducing spring was, for a long time, largely a matter of accident, and the true inwardness of its curves, quality of steel, and mode of tempering, have been the cause of an excessive amount of experimenting. Its apparent simplicity is as misleading to the average mechanic as the production of a first-class permanent magnet is to a blacksmith.

Of the many next-to-nothings which have their say in the gramophone, the reproducing sound box has shown up

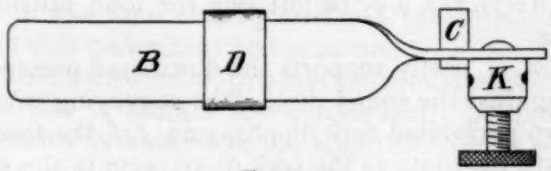

FIG. 9.

FIG. 10.

a goodly number; but they are now well known, and no difficulty is experienced in making many of like efficiency. As a matter of course, fair effects are attainable with crude apparatus, and what I state here refers to the production of the best results only.

As stated before, the spring stylus is clamped down to the upper part of the diaphragm box, and as it is originally curved, as shown in *Figs. 9* and *10*, this clamping down causes the free end, *y*, to press with considerable force against the lower part of the diaphragm box. At this point of pressure, a small metallic foot, *C*, covered with a thin soft rubber cushion, is interposed so as to give a minimum of elastic backing to the vibrations of the spring. Above the center of the diaphragm a soft rubber ring, *D*, is slipped

over the spring, and underneath it a metal sound post, *E*, which is screwed to the diaphragm, transmits the vibrations of the spring to the same. This sound post is adjustable by a screw-and-nut device, and the pressure it produces between diaphragm and spring is made to be moderately firm. The nut works stiffly on the sound post, and, besides this, the thread is waxed so as to avoid rattling. The binding post, *K*, holds a thick steel point.

A special damping device, consisting of a metal arch, *F*, and a soft rubber cushion pushed between the same and the spring, *B*, but not shown, modifies whatever outer resonance exists in the whole system of the reproducing sound box. This special damper is particularly advantageous for articulating effects, but may be left out for loud musical reproductions.

A post, *A*, partly supports the downward pressure of the stylus against the sound disc. The conveying tube, *H*, contains two perforated cork diaphragms, *J*, *J*, the functions of which are the same as the cork diaphragm in the recording sound box.

The spring stylus should stand at an angle of about 40° to the record surface, so as to permit easy action and freedom in vibrating. The needle point abrades under the continuous friction, and, when original zinc etchings are used, fresh needles must occasionally be used, so that no sharp edges may wear on the record groove. With hard rubber discs, this precaution is not vital, although a nicely rounded point of the needle often works better than a worn-off point. To correctly judge the condition of the needle point, and also for the purpose of studying records before, during, and after etching, I usually employ a lens, capable of magnifying about four diameters.

Duplicating Processes.—When I first exhibited the gramophone in this hall, I was able to show a fairly good duplicate of an original etching. This had been made by pressing the original in wax, and depositing copper on this wax mould, as is done in ordinary electrotyping. Some time afterwards a negative, that is, a plate having the lines raised instead of sunken, was made by depositing a copper shell on such an

electrotype copy. This negative was covered with electrolytic iron, or steel-faced, as it is called, and turned over to a rubber manufacturer, who, by means of this mould made some hard rubber copies by vulcanising rubber discs pressed in this negative. After further studying this over, it was found that an etched zinc plate could readily be impressed into softened hard rubber under heat and great pressure, and that, on cooling, the rubber disc had retained all the lines and marks most minutely, and represented a perfect hard-rubber negative of the original etching.

A hard-rubber negative of this character was then impressed in very hard beeswax, and, on this, copper was deposited, thereby getting a good copper mould or matrix. This matrix was then nickel-plated and rubber copies were made from this under heat and pressure.

Admirable, however, as this method would appear to be, there is a loss of surface and consequently of line work, whenever the wax became in the slightest degree softened during the mechanical part of the process, and a more direct mode of matrix-making became desirable. It was at all times evident, that if copper could be deposited directly on the original zinc plate and then lifted off, a perfect matrix should be the result. But on making the rounds among the large electrotyping firms in this country, none could be found able to do it, because none seemed to understand how to prepare a zinc plate to receive a copper deposit, without being attacked by a sulphate of copper solution. Coating the zinc plate in cyanide of copper solution proved efficient only when the copper deposit was made so thick as to affect the appearance of the zinc surface, and this meant a loss in the distinctness, or purity, of the sound from the copy discs.

It was while on a visit to Germany, that the problem was turned over to a very prominent electrotyping firm there, who succeeded, after a number of failures, in producing most accurate copper matrices by a direct deposition on zinc plates. Their method consists in covering the zinc with electrolytic brass; this is silvered and a copper shell is then deposited thereon, in a common sulphate of copper bath.

It is at best an exceedingly delicate piece of work, because, of all electrolytic solutions, the compounds of copper and zinc salts are the most fickle, and the judgment of the operator is continuously taxed to adapt his manipulation to the changing condition of the bath. Lately, however, this branch of gramophony has yielded to experience, and will soon be as easy of control as the rest of the art.

In pursuing my investigations for duplicating processes, I have had the able co-operation of your ingenious member and townsman, Mr. Max Levy, who supplied a number of missing links in our chain of research and manipulation.

General Remarks.—Thus far, the most difficult part of the gramophone work consisted in giving to the recording sound box a construction such that it would respond to, and record equally well, all kinds of sounds, from the male human voice (which is the easiest to correctly register), to the complicated effects of a duet with piano accompaniment. Many times did it become necessary to reconstruct portions of the recorder when it was found that, in a piano, for instance, the treble, or upper sounds, were brilliant and the lower ones extremely hard and jarring, or that, after a change had been made, the treble was hardly audible. A clarionet would sound all right with the exception of a single tone, which had a jarring admixture. Female voices were, for a long time, very impure in the higher notes. Then again would a baritone solo register well, but articulation was deficient and could not be readily understood. With band music, the mechanical effects on the recorder, of the various instruments, have to be carefully tested, and the players have to be placed at different distances from the recorder. Every time a change was made in a construction of a recorder, it was the occasion for a fresh series of experiments. Never in the whole course of the work was reliance placed for a certain effect on a single etching, but a number of plates were made so as to arrive at a safe conclusion, and even then fresh sources of error were often detected afterwards, either in the recording sound box, or in the sound collectors; and, in that case, all the results obtained up to that date were considered faulty, and a new

set of plates, comprising all kinds of voices and instruments, was etched, and the effects of the correction noted.

The chemical and other processes had to be continuously watched for fresh errors due to unknown causes. Once when plate after plate etched through outside of the line work, the cause was eventually traced to a greater water pressure when the alcohol was washed from the freshly traced record disc. This washing off of the alcohol originated, by the way, in a peculiar incident. You will, perhaps, remember that, in the early experiments, the disc, after the record was made on it, was placed edgewise against a support, and the alcohol dried in the air, or by fanning. One day a few drops of water accidentally fell on the wet disc and washed off the alcohol. At first it was thought that the delicate etching ground was disturbed and that the plate was spoiled; but, when it was put into the acid, that portion where the alcohol had been washed off etched faster and smoother than the other portion, and after studying it over I concluded that the alcohol dissolved a very small percentage of the fatty etching ground, and, on evaporating, would re-deposit an extremely delicate layer of fat over the traced line and thereby retard and roughen the etching. Since then every plate is washed immediately after tracing,

In the first winter season the cleaned plates would not take the etching ground readily, and the film was streaky and cloudy, and would etch through in spots. After several weeks of failure, I, at last, discovered that it was due to the fact that the room in which the plates were cleaned was much cooler than that in which they were coated, and that an invisible layer of moisture deposited on the plate by the change of temperature, and prevented the fatty film from adhering to the zinc; since then all the work is done in a well-warmed room, and the plate, which cools considerably while being cleaned with benzine, is slightly warmed over a burner before coating it with the fatty film.

Again, an iridium point would trace a poor record, and the etching was rough, and the sound harsh, and this was found to be occasioned by heating the plate too strongly in the coating process, which consolidated the fat to such an extent, that the stylus would not cut the film readily.

The reproducing machine before you is intended for discs 7 inches or less in diameter. The lines are 96 to the inch, and the diameter of the circular band, in which record lines are traced, is about 1½ inches wide. The velocity with which a 7-inch disc should be rotated is about seventy turns a minute, so that the duration of sound on such a disc can be fully two minutes. For ordinary speaking, however, when the amplitude of vibrations is but small, the lines can be traced closer together, and a duration of three minutes for a 7-inch disc is entirely feasible.

The reproducing needle points are made of good steel, and, in the absence of special steel points, extra thick broken-off darning needles are excellent substitutes.

The reproducing sound box is compactly built, and may be placed in the hands of children without danger of becoming damaged.

Seven-inch discs can readily be mailed for a few cents all over the world, and are then protected by pasteboard from damage in transit. Should they become bent they can easily be flattened by putting them in a letter-press over night. I am carrying on a continuous correspondence by means of gramophone discs with friends across the ocean, and others have occasionally availed themselves of this means of communication. The voices of several members among my own relatives, now deceased, are thus recorded and may be recalled at any time.

Many hundreds of pounds of zinc and many gallons of acid have been used up in this work, and as each plate averaged a half an hour for its entire completion, you can readily account for the delay which the development of the gramophone has suffered. Fortunately, time was not an object, because, for its peculiar purposes of providing a cheap, durable and efficient talking machine, the gramophone, even after the delay, stands without competition, and I have been spared the spur of commercial rivalry to add to the perplexities of the situation, and could, with due leisure and caution, feel my way through the various technical problems and their labyrinthian courses.

I cannot too strongly warn future experimenters and gramophone operators against false conclusions or apparently logical tests. It is not with ordinary mechanics that talking machines deal. They are to imitate, in a coarse, mechanical way, the infinitesimal movements of the complicated inner ear, and the soft and extremely flexible motions of the vocal organs. At every new experimental step lurk the "next-to-nothings" of science, and as a training for young physicists, the technique of the gramophone should offer decided attractions.

On the GROWTH and SUSTAINING POWER of ICE.

By P. Vedel, C. E., M. West. Soc. Eng.

[*Concluded from p. 370.*]

For G and S, Thompson and Tait deduce the expressions:

$$\begin{cases} G = A \dfrac{d^2 z}{d r^2} + c \dfrac{d z}{r\, d r} = A \left(\dfrac{d^2 z}{d r^2} + \dfrac{a}{r} \dfrac{d z}{d r}\right) \\ S = A \dfrac{d}{d r} \nabla^2 z \end{cases} \tag{12}$$

whereas the bending moment around a radius is:

$$L = c \frac{d^2 z}{d r^2} + A \frac{d z}{r\, d r} = A \left(a \frac{d^2 z}{d r^2} + \frac{1}{r} \frac{d z}{d r}\right)$$

Returning now to equation (11), the exterior force Z is generally composed of the load carried by the ice, p, per square unit of its surface; the weight of the ice itself, $W \delta h$, if W is the weight of a cubic unit of water and δ the specific gravity of ice; and the upward pressure of the water on the immerged part of the ice. If the ice is floating on the water this pressure is $W \delta h + W z$; if the water has been withdrawn from under it no buoyancy can be acting; intermediate cases, where the ice is partially floating, need not be considered. Thus:

$$Z = \begin{cases} p + W \delta h \\ p - W z \end{cases} \tag{13}$$

according as the ice is lying free or supported by the water. Inasmuch as p is considered constant, Z is in the first case independent of r.

Equation:

$$\frac{d^4 z}{d r^4} + \frac{2}{r}\frac{d^3 z}{d r^3} - \frac{1}{r^2}\frac{d^2 z}{d r^2} + \frac{1}{r^3}\frac{d z}{d r} = \frac{p + W \delta h}{A}$$

is, therefore, satisfied by the integral:

$$z = \frac{p + W \delta h}{64 A} r^4 + C r^2 \log r + C_1 r^2 + C_2 \log r + C_3 \quad (14)$$

The more complicated equation:

$$\frac{d^4 z}{d r^4} + \frac{2}{r}\frac{d^3 z}{d r^3} - \frac{1}{r^2}\frac{d^2 z}{d r^2} + \frac{1}{r^3}\frac{d z}{d r} = \frac{p - W z}{A}$$

can only be approximately integrated. An approximation will (14) be found when p be substituted for $p + W \delta h$. A closer approximation is found by introducing for z its excess, ζ, over the ordinate of a parabola: $z_1 = d - B r^2$, where d is the maximum deflection of the ice sheet, corresponding to $r = 0$. Equating, therefore:

$$z = d - B r^2 + \zeta$$

differentiating and substituting we find:

$$\frac{d^4 \zeta}{d r^4} + \frac{2}{r}\frac{d^3 \zeta}{d r^3} - \frac{1}{r^2}\frac{d^2 \zeta}{d r^2} + \frac{1}{r^3}\frac{d \zeta}{d r} = \frac{p}{A} - \frac{W}{A}(d - B r^2) - \frac{W}{A}\zeta$$

Conceive the parabola or its parameter, B, determined so as to approach as near as possible to the actual surface of the ice sheet, then ζ will be a small quantity, and

$$\frac{W}{A}$$

being also a very small fraction, the product

$$\frac{W}{A}\zeta$$

may be neglected. But then the integral of the equation is:

$$\zeta = \frac{p - W d}{64 A} r^4 + \frac{W B}{576 A} r^6 + c r^2 \log r + c_1 r^2 + c_2 \log r + c_3$$

whence:

$$z = \frac{W B}{576 A} r^6 + \frac{p - W d}{64 A} r^4 + C r^2 \log r + C_1 r^2 + C_2 \log r + C_3 \quad (15)$$

In these expressions, as in (14), the small and large C's designate arbitrary constants. To determine the additional constants d and B, we have the conditions that $z = d$ for $r = o$, and may, as a first approximation, assume the paraboloid of revolution to intersect the ice sheet at shore or: $d = B R^2$.

For both (14) and (15) we find:

$$C_3 = d, \; C_2 = 0.$$

The condition referring to the shearing stress gives for (14):

$$C = \frac{P}{8 \pi A}$$

and for (15) approximately the same, or in reality C perhaps a little less. By (12) the couple G is found:

$$G = \frac{p + W \delta h}{16} (3 + a) r^2 + \frac{P}{4\pi} (1 + a) \log r + \frac{P}{8\pi} (3 + a) + 2 C_1 A (1 + a) \tag{16}$$

$$G = \frac{W B}{96} (5 + a) r^4 + \frac{p - W d}{16} (3 + a) r^2 + \frac{P}{4\pi} (1 + a) \log r + \frac{P}{8\pi} (3 + a) + 2 C_1 A (1 + a) \tag{17}$$

and the remaining two constants, C_1 and d, are determined by the condition that expressions (14) and (16) and expressions (15) and (17) shall respectively vanish, for $r = R$.

Thus, (16) will be:

$$-G = \frac{p + W \delta h}{16} (3 + a)(R^2 - r^2) + \frac{P}{4\pi} (1 + a) \log \frac{R}{r}$$

whereas (17) will lead to a somewhat complicated expression. Both may be simplified by substituting for a its value 0·3, whence respectively:

$$-G = 0{\cdot}21 \, (p + W \delta h)(R^2 - r^2) + 0{\cdot}10 \, P \log \frac{R}{r} \tag{18}$$

$$-G = 0{\cdot}055 \, W \frac{0{\cdot}064 \, p \, R^2 + 0{\cdot}050 \, P}{A + 0{\cdot}044 \, W R^4} (R^4 - r^4) + 0{\cdot}21 \left(p - W R^2 \frac{0{\cdot}064 \, p \, R^2 + 0{\cdot}050 \, P}{A + 0{\cdot}044 \, W R^4}\right)(R^2 - r^2) + 0{\cdot}10 \, P \log \frac{R}{r} \tag{19}$$

To determine now the supporting power of the ice sheet, we must find the maximum value of G. But by inspection of (18) we see that no real maximum exists, but that G reaches its greatest value when r is as small as possible. Now it must be remembered that P is the sum of the weights theoretically acting in single points, circularly arranged around the center and inside the circle of radius r. The smallest possible value of r corresponding to a given P is, therefore, the radius of the circle on the circumference of which the outmost of the weights included in P are acting. $P = 0$ corresponds to $r = 0$ and the second term of (18) vanishes. In deducing our formulas we have in reality silently assumed P to be acting at or in a very short distance from the center; only then the conditions by which the arbitrary constants were determined are correct. Suppose P to be distributed over a very small circular area of radius $r = \rho$, then the greatest bending moment will be at that distance from the center, and its value G determined by (18) with ρ substituted for r.

Equation (19), on the other hand, may have a maximum or minimum. Differentiating and equating the ratio of variation of G to naught, we find:

$$\frac{r^2}{R^2} = 0{\cdot}93\left(1 - \frac{p}{W d}\right) \pm \sqrt{0{\cdot}86\left(1 - \frac{p}{W d}\right)^2 - 0{\cdot}45\,\frac{P}{W d R^2}} \qquad (20)$$

which must be < 1.

That this value of r shall not be imaginary must:

$$W d - p > 0$$

and

$$(W d - p)^2 > 0{\cdot}5233\,\frac{P W d}{R^2}$$

whence:

$$R(W d - p) > 0{\cdot}72\sqrt{P W d}$$

or:

$$R^8 + 1{\cdot}25\,\frac{P}{p}R^6 - \left(100\,\frac{A}{W} - 3{\cdot}25\,\frac{P^2}{p^2}\right)R^4 - 333{\cdot}75\,\frac{A}{W}\frac{P}{p}R^2 + \left(2500\,\frac{A}{W} - 65{\cdot}50\,\frac{P^2}{p^2}\right)\frac{A}{W} > 0 \qquad (21)$$

an equation of fourth degree in R^2 and second degree in:

$$\frac{P}{p}$$

Differentiating a second time we find

$$\frac{d^2 G}{d r^2}$$

to have the same sign as

$$44\ W d\ \frac{r^2}{R^2} - 41\ (W d - p)$$

which is positive or negative according as:

$$\frac{r^2}{R^2} \gtrless \frac{41}{44}\left(1 - \frac{p}{W d}\right) = 0{\cdot}93\left(1 - \frac{p}{W d}\right)$$

The upper sign in (20), therefore, corresponds to a minimum, the lower sign to a maximum of G, and *vice versa* for $-G$. And inasmuch as G from 0, corresponding to $r = R$, decreases with r decreasing to the greater of the two values (20), then increases until r reaches the lower value (20), and then again decreases with r, the numerical maximum may correspond to the upper sign of (20) and a numerical minimum or smaller maximum to the lower sign.

If R is too small to satisfy equation (21) the same applies to (19) as to (18); G has no real maximum, but is numerically as great as possible when r is as small as possible, *i.e.*, $r = \rho$. Otherwise there is a maximum, corresponding to the value of r, determined by (20) taken with its upper or lower sign. But still the value of G corresponding to $r = \rho$ may be greater than the maximum.

With the inch and the pound as units we have:

$$W = 0{\cdot}036\,;\ \delta = 0{\cdot}92\,;\ A = 0{\cdot}09\ M\ h^3 = 1071 \times 10^5\ h^3$$

Reducing farther the hyperbolic logarithms to common logarithms by introducing the factor 2·30, and substituting G for the numerical value of $\mp\ G$, and in (18) ρ for r, we find:

$$G = (0{\cdot}21\ p + 0{\cdot}007\ h)\ (R^2 - \rho^2) + 0{\cdot}23\ P\ log\ \frac{R}{\rho} \quad (22)$$

$$\pm G = \frac{13\,p\,R^2 + 10\,P}{1071 \times 10^{10}\,h^3 + 158\,R^4}(R^4 - r^4) +$$

$$(0{\cdot}21\,p - R^2\,\frac{48\,p\,R^2 + 38\,P}{1071 \times 10^{10}\,h^3 + 158\,R^4})(R^2 - r^2) +$$

$$0{\cdot}23\,P\,log\,\frac{R}{r} \qquad (23)$$

where r is either ρ or the value determined by (20).

Equations (22) and (23) determine the breaking moments which, taken per unit of length, should be equated to the moment of resistance, or $\frac{1}{6}\,Ch^2$, when C denotes the coefficient of resistance, or say 200 pounds per square inch. If, for convenience sake, R, r and ρ be expressed in feet, p in pounds per square foot, h in hundredths of inches, then we shall have:

$$h^2 - 3\,h\,(R^2 - \rho^2) - 63\,p\,(R^2 - \rho^2) - 69\,P\,log\,\frac{R}{\rho} = 0 \qquad (24)$$

$$h^5 \mp (63\,p\,(R^2 - r^2) + 69\,P\,log\,\frac{R}{r})\,h^3 + 0{\cdot}3\,R^4\,h^2 \mp$$

$$(8\,p\,R^2 + 6\,P)(R^4 - r^4) \pm (9\,p\,R^4 + 22\,P\,R^2)(R^2 - r^2) \mp$$

$$21\,P\,R^4\,log\,\frac{R}{r} = 0 \qquad (25)$$

respectively for the ice-sheet unsupported or supported by the underlying water. Here r is determined by (20) or, in the adopted units:

$$1{\cdot}07\,r^2 = R^2 - k\,p \pm 1\sqrt{(R^2 - k\,p)^2 - 0{\cdot}52\,k\,P} \qquad (26)$$

where:

$$k = \frac{R^2}{144\,W\,d} = \frac{h^3 + 0{\cdot}31\,R^4}{0{\cdot}35\,P + 0{\cdot}45\,p\,R^2}$$

or, if this is an imaginary quantity or the corresponding value of G is numerically greater,

$$r = \rho$$

These somewhat unwieldy general expressions are considerably simplified when either

$$P = 0$$

or

$$p = 0$$

If

$$P = 0$$

then

$$p = 0$$

and (24), (25), (26) give:

$$h^2 - 3\,h\,R^2 - 63\,p\,R^2 = 0$$

$$p = \frac{h^2}{63\,R^2} - \frac{h}{21} \tag{27}$$

$$h^3 \mp 63\,p\,(R^2 - r^2)\,h^2 + 0{\cdot}3\,R^4\,h^2 \pm p\,R^2\,(R^4 - 9\,R^2\,r^2 + 8\,r^4) = 0$$

$$p = \pm \frac{h^2\,(h^3 + 0{\cdot}3\,R^4)}{63\,h^3\,(R^2 - r^2) - R^2\,(R^4 - 9\,R^2\,r^2 + 8\,r^4)} \tag{28}$$

where:

$$r^2 = \begin{cases} \dfrac{2\,(R^2 - k\,p)}{1{\cdot}07} = 0{\cdot}58\,R^2 - 4{\cdot}15\,\dfrac{h^3}{R^2} & \left\{ \begin{array}{l} \text{corresponding to} \\ \text{the upper sign.} \end{array} \right. \\ 0 & \left\{ \begin{array}{l} \text{corresponding to} \\ \text{the lower sign.} \end{array} \right. \end{cases}$$

if

$$h^3 < \frac{58}{415}\,R^4$$

or

$$h < 0{\cdot}52\,R\,\sqrt[3]{R}$$

and otherwise, or if the corresponding value of p is smaller

$$r = 0$$

corresponding to the upper sign:

$$p = \frac{h^2\,(h^3 + 0{\cdot}3\,R^4)}{R^2\,(63\,h^3 - R^4)}$$

If, on the contrary,

$$p = 0$$

the equations will be:

$$h^2 - 3\,h\,(R^2 - \rho^2) - 69\,P\,log\,\frac{R}{\rho} = 0$$

$$P = \frac{h^2 - 3\,h\,(R^2 - \rho^2)}{69\,(log\,R - log\,\rho)} \tag{29}$$

$$h^5 \mp 69\,P\,log\,\frac{R}{r}\,h^3 + 0{\cdot}3\,R^4\,h^2 \pm P\,(16\,R^4 - 22\,R^2\,r^2 + 6\,r^4) \mp 21\,P\,R^4\,log\,\frac{R}{r} = 0$$

$$P = \pm \frac{h^2\,(h^3 + 0{\cdot}3\,R^4)}{(69\,h^3 + 21\,R^4)\,log\,\frac{R}{r} - (16\,R^4 - 22\,R^2\,r^2 + 6\,r^4)} \quad (30)$$

where:

$$r^2 = 0{\cdot}93\,R^2 \pm \sqrt{0{\cdot}47\,R^4 - 1{\cdot}29\,h^3}$$

if:

$$h^3 < \frac{47}{129}\,R^4$$

or

$$h < 0{\cdot}71\,R\sqrt[3]{R}$$

and otherwise, or if the corresponding value of P is smaller than the geometrical minimum, $r = \rho$. The upper sign in r^2 corresponds to the upper sign of P, the lower to the lower. If the upper value of r is $> R$, it is, of course, impossible as a solution; the same if the lower value is $< \rho$. The upper sign corresponds to $r = \rho$.

Equations (27) and (29) show that when the ice is not supported by the water we must always have:

$$h > \begin{cases} 3\,R^2 \\ 3\,(R^2 - \rho^2) \end{cases}$$

respectively. In equations (28) and (30) it must be tried whether either of the two maxima or minima, or r as small as possible, *i. e.*, $r = \rho$, gives the smallest value for p or P.

Let, for illustration, these formulas be applied to the case where the diameter of the lake is $D = 2\,R = 10^n$ feet, and, when P does not vanish, $\rho = 2$ feet. Equations (27) and (29) then give:

$$p = \frac{6\,h^2}{10^{2n+2}} - \frac{5\,h}{10^2}$$

$$P = h\,\frac{h - 75 \times 10^{2n-2} + 12}{69\,n - 42}$$

Equation (28) gives:

$$p = \begin{cases} \dfrac{6\,h^2}{10^{2n+2}} \dfrac{h^3 + 188 \times 10^{4n-4}}{h^3 - 10^{4n-3}} \\ 2 \times 10^{2n-3}\, h^2 \dfrac{h^3 + 188 \times 10^{4n-4}}{h^6 + 14 \times 10^{4n-3}\, h^3 + 48 \times 10^{8n-6}} \end{cases}$$

according as

$$h \gtrless 3{\cdot}9 \times 10^{\frac{4(n-1)}{3}}$$

the second expression implying as a necessary condition that

$$h < 4{\cdot}4 \times 10^{\frac{4(n-1)}{3}}$$

but this limit being lowered by the additional condition that the smaller of the two values for p should be used.

And (30) gives:

$$P = h^2 \frac{h^3 + 188 \times 10^{4n-4}}{(69n-42)h^3 + (131n-179) \times 10^{4n-2} + 22 \times 10^{2n} - 96}$$

this value of P being always smaller than the one corresponding to the geometrical minimum, which is:

$$P = 372 \times 10^{8n-6}\, h^2$$

$$\times \frac{h^3 + 188 \times 10^{4n-4}}{h^9 + 135 \times 10^{4n-3}\, h^6 - 987 \times 10^{8n-5}\, h^3 + 139 \times 10^{12n-6}}$$

and only possible if

$$h < 6{\cdot}1 \times 10^{\frac{4(n-1)}{3}}$$

The following table has been calculated from these formulas and applies to ice supported by the underlying water. The thickness of the ice is indicated by H in inches instead of by h in hundredths of inches. The uniformly distributed weight per square foot has, for $n = 1$ and $n = 2$, been determined by the first of the two expressions for p, inasmuch as $h > 84$. The total uniformly distributed load $\frac{1}{4}\pi D^2 p$ is for $n \geq 4$ practically constant for the same thickness of ice.

TABLE I.—VALUES OF p IN POUNDS PER SQUARE FOOT AND $\frac{1}{4}\pi D^2$ AND P IN POUNDS.

D (in ft.)		10			100			1,000			10,000			100,000			1,000,000		
$\frac{1}{4}\pi D^2$		78·54			7,854			$7{,}854 \times 10^2$			$7{,}854 \times 10^4$			$7{,}854 \times 10^6$			$7{,}854 \times 10^8$		
n		1			2			3			4			5			6		
$3{\cdot}9 \times 10^{\frac{4(n-1)}{3}}$		3·9			84			1,810			39,000			840,216			181,022,400		
	p	$\frac{1}{4}\pi D^2 p$	P	p	$\frac{1}{4}\pi D^2 p$	P	p	$\frac{1}{4}\pi D^2 p$	P	p	$\frac{1}{4}\pi D^2 p$	P	p	$\frac{1}{4}\pi D^2 p$	P	p	$\frac{1}{4}\pi D^2 p$	P	p	$\frac{1}{4}\pi D^2 p$	P
H ($= 0{\cdot}01\,h$) in inch.	$6\,H^2$.	$471{\cdot}2\,H^2$	$370{\cdot}37\,H^2$							$\frac{783}{10^2}H^2$	$6152{\cdot}3\,H^2$	$54{\cdot}49\,H^2$	$\frac{783}{10^6}H^2$	$6152{\cdot}3\,H^2$	$39{\cdot}50\,H^2$	$\frac{783}{10^{11}}H^2$	$6152{\cdot}3\,H^2$	$30{\cdot}97\,H^2$
1	6	471	370	0·19	1,500	161	0·018	6,150	88	8×10^{-6}	6,152	54	8×10^{-7}	6,152	39	8×10^{-8}	6,152	31
2	24	1,885	1,482	0·30	2,356	464	0·031	24,559	351	$31 \times$ "	24,609	218	$31 \times$ "	24,609	158	$31 \times$ "	24,609	107
3	54	4,241	3,333	0·58	4,554	972	0·070	55,017	790	$71 \times$ "	55,371	490	$71 \times$ "	55,371	355	$71 \times$ "	55 371	279
4	96	7,539	5,926	0·99	7,773	1,693	0·123	96,958	1,403	$125 \times$ "	98,437	872	$125 \times$ "	98,437	632	$125 \times$ "	98,437	496
5	150	11,780	9,259	1·52	11,968	2,608	0·190	149,336	2,165	$196 \times$ "	153,808	1,362	$196 \times$ "	153,808	987	$196 \times$ "	153,808	774
6	216	16,963	13,333	2·18	17,120	3,768	0·268	210,558	3,147	$282 \times$ "	221,483	1,962	$282 \times$ "	221,483	1,422	$282 \times$ "	221,483	1,115
7	294	23,089	18,148	2·96	23,224	5,119	0·355	278,424	4,270	$384 \times$ "	301,463	2,670	$384 \times$ "	301,463	1,936	$384 \times$ "	301,463	1,518
8	384	30,157	23,704	3·85	30,276	6,680	0·446	350,257	5.556	$501 \times$ "	393,747	3,487	$501 \times$ "	393,747	2,528	$501 \times$ "	393,747	1,982
9	485	38,167	30,000	4·87	38,274	8,449	0·539	423,032	6,998	$634 \times$ "	498,336	4,414	$634 \times$ "	498,336	3,200	$634 \times$ "	498,336	2,509
10	600	47,120	37,037	6·01	47,217	10,427	0·629	493,679	8,590	$783 \times$ "	615,230	5.449	$783 \times$ "	615,230	3,950	$783 \times$ "	615,230	3,097
11	726	57,015	44,815	7·27	57,105	12,614	0·712	559,346	10,323	$947 \times$ "	744,428	6,593	$947 \times$ "	744,428	4,780	$947 \times$ "	744,428	3,747
12	864	67,853	53,333	8·65	67,936	15,009	0·786	617,646	12,189	$1,128 \times$ "	885,931	7,847	$1,128 \times$ "	885,931	5,688	$1,128 \times$ "	885,931	4,460

Referring to the army rules, we see that actually for $D \leq$ 10,000 feet = about two miles, a two-inch ice sheet will safely support a man of 200 pounds weight, whereas a man on horseback, weighing, with the horse, 1,200 pounds, if this weight were acting over an area of only 4 feet diameter, would need 5-inch ice.

Ice not supported by the water, as the formulas show, cannot carry its own weight unless $h > 8 \times 10^{2n-1}$. Except for very small ponds, the ice will therefore crack and sag when the water recedes from under it.

In what precedes, we have considered the water-basin as circular, or at least approximately so. The formulas therefore apply with a fair approximation to most any lake when its average diameter is taken as D. For Lake Superior, D may be taken as 200 miles; for Lake Michigan, 180; Lake Huron, 175; Lake Erie, 113; and Lake Ontario, 97 miles. But if the ice covers a canal or a river, other formulas are required.

Considering a unit length of the canal and its ice-cover—just as we do when we calculate a retaining wall—and returning to the general equations, we deduce from (10) the equation:

$$A \frac{d^4 z}{d x^4} = Z = \begin{cases} p + W \delta h \\ p - W z \end{cases}$$

which takes the place of (11) and (13). The arbitrary constants of the integrals:

$$z = \frac{p + W \delta h}{24 A} x^4 + C x^3 + C_1 x^2 + C_2 x + C_3 \quad (31)$$

$$z = \frac{p}{W} + e^{\sqrt[4]{\frac{W}{4A}} x} \left(C \cos \sqrt[4]{\frac{W}{4A}}\, x + C_1 \sin \sqrt[4]{\frac{W}{4A}}\, x\right) +$$

$$e^{-\sqrt[4]{\frac{W}{4A}} x} \left(C_2 \cos \sqrt[4]{\frac{W}{4A}}\, x + C_3 \sin \sqrt[4]{\frac{W}{4A}}\, x\right) \quad (32)$$

where e is the base of the natural logarithms, are determined by the conditions that

$$\frac{d z}{d x} = 0, \text{ for } x = 0;$$

and

$$z = 0$$

and

$$G = A \frac{d^2 z}{d x^2} = 0$$

at shore ($x = b$); and

$$S = A \frac{d^3 z}{d x^3} = \int_0^x Z \, d x + \tfrac{1}{2} P$$

This gives for the free-lying ice:

$$C = \frac{P}{12 A}, \; C_2 = 0$$

and:

$$-G = \frac{p + W \delta h}{2} (b^2 - x^2) + \frac{P}{2} (b - x) \qquad (33)$$

It gives for the water-borne ice:

$$C_2 - C = C_1 + C_3 = \frac{P}{2 W} \sqrt[4]{\frac{W}{4 A}}$$

and with γ for

$$\sqrt[4]{\frac{W}{4 A}}$$

and *Cos x*, *Sin x* for the hyperbolic functions:

$$\frac{e^x + e^{-x}}{2}$$

or $cos \sqrt{-1}\, x$ and

$$\frac{e^x - e^{-x}}{2}$$

or $\sqrt{-1}\, sin \sqrt{-1}\, x$

$$-G (Cos\ 2\gamma b + cos\ 2\gamma b) = \frac{p}{2\gamma^2} [Sin\ \gamma (b + x)\ sin\ \gamma (b - x)$$

$$+ sin\ \gamma (b + x)\ Sin\ \gamma (b - x)] + \frac{P}{4\gamma} [Cos\ \gamma x\ sin\ \gamma (2b - x)$$

$$- sin\ \gamma x\ Cos\ \gamma (2b - x) + cos\ \gamma x\ Sin\ \gamma (2b - x) - Sin\ \gamma x\ cos\ \gamma (2b - x)] \qquad (34)$$

The greatest value of $-G(33)$ corresponds to x as small as possible, or $x = 0$ when $P = 0$, and otherwise $x = \rho$ when P covers a length 2ρ. But $-G(34)$ may have a maximum or minimum. Differentiating, remembering that

$$\frac{d\,Cos\,x}{d\,x} = Sin\,x$$

and

$$\frac{d\,Sin\,x}{d\,x} = Cos\,x$$

and equating the ratio of variation of G to naught, we find:

$$p\,[Cos\,\gamma\,(b+x)\,sin\,\gamma\,(b-x) - sin\,\gamma\,(b+x)\,Cos\,\gamma\,(b-x) + cos\,\gamma\,(b+x)\,Sin\,\gamma\,(b-x) - Sin\,\gamma\,(b+x)\,cos\,\gamma\,(b-x)] = P\gamma\,[Cos\,\gamma\,x\,cos\,\gamma\,(2b-x) + cos\,\gamma\,x\,Cos\,\gamma\,(2b-x)] \quad (35)$$

which determines the value of x that makes G a maximum or minimum. The numerically greatest value of G, whether corresponding to this x, or to x as small as possible, *i. e.*, $x = 0$ or $x = \rho$, should be equated to the moment of resistance $\frac{1}{6} C h^2$, or

$$\frac{200}{6} h^2$$

if h is expressed in inches.

With (as before) $W = 0{\cdot}036$, $\delta = 0{\cdot}92$, $A = 1071 \times 10^5\, h^3$, equation (33) gives:

$$h^2 - 7h\,(b^2 - \rho^2) - 150\,p\,(b^2 - \rho^2) - 150\,P\,(b - \rho) = 0 \quad (36)$$

where P is expressed in pounds per linear foot, p in pounds per square foot, b, x, ρ in feet, and h in hundredths of inches. In (34) and (35) is, with the same units:

$$\gamma = \frac{1}{10{\cdot}44\,h^{\frac{3}{4}}}$$

and for $\gamma\,x$ or $\gamma\,b$ to substitute

$$\frac{1{\cdot}15\,x}{h^{\frac{3}{4}}}.$$

or

$$\frac{1{\cdot}15\,b}{h^{\frac{3}{4}}}$$

and for P and p to substitute

$$\frac{P}{12}$$

and

$$\frac{p}{144}$$

G is to be equated to:

$$\frac{1}{300} h^2$$

But it is unnecessary to reproduce the complicated equation thus deduced. In any particular case the approximate solution of (34) and (35) will offer no great difficulty when, simultaneously with the tables of the circular functions, those of the hyperbolic functions are consulted. Such tables have been published by Ligowski and others, and are to be found in Hütte: "Des Ingenieurs Taschenbuch."

If either $P = 0$ or $p = 0$, equation (36) gives:

$$h^2 - 7\, h\, b^2 - 150\, p\, b^2 = 0$$

and

$$h^2 - 7\, h\, (b^2 - \rho^2) - 1800\, P\, (b - \rho) = 0$$

The ice, when not supported by the water, must, therefore, always have a thickness:

$$h > 7\, b^2$$

or

$$> 7\, (b^2 - \rho^2)$$

respectively.

Equation (35) gives, with γ_1 for

$$\frac{1{\cdot}15}{h^{\frac{3}{4}}}$$

$$Cos\, \gamma_1 (b + x)\, sin\, \gamma_1 (b - x) + cos\, \gamma_1 (b + x)\, Sin\, \gamma_1 (b - x) =$$
$$Sin\, \gamma_1 (b + x)\, cos\, \gamma_1 (b - x) + sin\, \gamma_1 (b + x)\, Cos\, \gamma_1 (b - x)$$

and

$$Cos\, \gamma_1 x\, cos\, \gamma_1 (2\, b - x) = - cos\, \gamma_1 x\, Cos\, \gamma_1 (2\, b - x)$$

or, with $Tg\ x$ for

$$\frac{Sin\ x}{Cos\ x} = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$

$$Tg\ \gamma_1 x\ (Tg\ \gamma_1 b\ tg\ \gamma_1 b - 1) = tg\ \gamma_1 x\ (Tg\ \gamma_1 b\ tg\ \gamma_1 b + 1) \quad (37)$$

$$Sin\ 2\ \gamma_1 b\ Tg\ \gamma_1 x - sin\ 2\ \gamma_1 b\ tg\ \gamma_1 x = Cos\ 2\ \gamma_1 b + cos\ 2\ \gamma_1 b \quad (38)$$

And (34), equated to

$$\frac{1}{300} h^2$$

gives:

$$h^{\frac{1}{2}} = \pm\ 228\ p$$

$$\frac{Cos\ \gamma_1 b . cos\ \gamma_1 b . Cos\ \gamma_1 x . cos\ \gamma_1 x (Tg\ \gamma_1 b . tg\ \gamma_1 b - Tg\ \gamma_1 x . tg\ \gamma_1 x)}{Cos\ 2\ \gamma_1 b + cos\ 2\ \gamma_1 b} \quad (39)$$

$$h^{\frac{1}{4}} = \pm\ 65\ P . Cos\ \gamma_1 x . cos\ \gamma_1 x$$

$$\left[\frac{Sin\ 2\ \gamma_1 b + sin\ 2\ \gamma_1 b + Tg\ \gamma_1 x . tg\ \gamma_1 x\ (Sin\ 2\ \gamma_1 b - sin\ 2\ \gamma_1 b)}{Cos\ 2\ \gamma_1 b + cos\ 2\ \gamma_1 b} - Tg\ \gamma_1 x - tg\ \gamma_1 x\right] \quad (40)$$

where it should be remembered that γ_1 contains h, and x, which must always be $< b$ and ≥ 0 or ρ, is either determined by (37), (38) or equal to 0 or ρ, according to which of these values makes the term on the right hand side of (39), (40) numerically as great as possible.

Equation (37) gives no possible solution when b is so small that

$$\gamma_1 b < \frac{\pi}{2}$$

and consequently

$$\gamma_1 x \text{ also} < \frac{\pi}{2}$$

for the circular tangent is then greater than the hyperbolic tangent. But when $\gamma_1 b$ is approximately equal to or greater than 2, the hyperbolic tangent is very nearly equal to 1; and as $\gamma_1 x$ must be

$$> \frac{\pi}{2}$$

if (37) shall have any solution, we have:

$$Tg\,\gamma_1 x = Tg\,\gamma_1 b = 1$$

and consequently

$$tg\,\gamma_1 x = \frac{tg\,\gamma_1 b - 1}{tg\,\gamma_1 b + 1}$$

$$\gamma_1 x = \gamma_1 b - \frac{\pi}{4} - n\pi$$

where n is an arbitrary, positive ($x < b$), whole number. In (39) only $Cos\,\gamma_1 x$ varies numerically with n, decreasing with it; that the right-hand side of the equation may be as great as possible, we must, therefore, make $n = 0$*. Thus, $2\,\gamma_1 b > 4{\cdot}7$.

But for the hyperbolic functions we have approximately:

$$Cos\,\varphi = Sin\,\varphi = \tfrac{1}{2} e^{\varphi}$$

when $\varphi > 2$ and almost exactly when $\varphi > 5$.

Hence, (39), with, for simplicity's sake, H for $0{\cdot}01\ h$, may be transformed to:

$$H^{\frac{1}{4}} = 8\,p \quad \frac{Cos\left(\gamma_1 b - \frac{\pi}{4}\right)}{Cos\,\gamma_1 b}$$

or

$$p = \frac{\sqrt{H}}{8} \frac{Cos\,\gamma_1 b}{Cos\left(\gamma_1 b - \frac{\pi}{4}\right)}$$

or, approximately, when $\gamma_1 b$ is great:

$$p = \frac{\sqrt{H}}{8} e^{\frac{\pi}{4}} = 0{\cdot}271\ \sqrt{H} \tag{41}$$

This value, to which p converges when $\gamma_1 b$ increases, is independent of b.

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* To other values of n correspond other maxima or minima of G, but relatively smaller. The corresponding x determines dangerous points where breaks might occur.

To $x = 0$ corresponds:

$$p = \frac{\sqrt{H}}{23} \frac{Cos\, 2\gamma_1 b + cos\, 2\gamma_1 b}{Sin\, \gamma_1 b\, sin\, \gamma_1 b} \tag{42}$$

or, approximately, when $\gamma_1 b$ is great:

$$p = \frac{\sqrt{H}}{23} \frac{Sin\, \gamma_1 b}{sin\, \gamma_1 b} = 0{\cdot}044 \sqrt{H}\, \frac{Sin\, \gamma_1 b}{sin\, \gamma_1 b}$$

which, for $\gamma_1 b > 2{\cdot}25$, is greater than (41), and, therefore, inapplicable.

Equation (38) gives no possible solution when

$$2\gamma_1 b < \frac{\pi}{2}$$

because *Cos* is always > *Sin* and $Tg < 1$. It gives for $\gamma_1 b$ sufficiently great (> 1 or 2):

$$tg\, \gamma_1 x = -\cot 2\gamma_1 b \qquad \gamma_1 x = 2\gamma_1 b - \frac{\pi}{2} - n\pi$$

In (40) only *Cos* $\gamma_1 x$ varies numerically with n, which, therefore, should be taken as small as possible consistent with the condition that:

$$\gamma_1 x < \gamma_1 b$$

or

$$n > \frac{\gamma_1 b}{\pi} - \frac{1}{2}$$

But (40) may be transformed to:

$$H^{\frac{1}{4}} = \frac{65\, P}{316{\cdot}2} \frac{Cos\, (2\gamma_1 b - \frac{\pi}{2} - n\pi)}{Cos\, 2\gamma_1 b}$$

or, approximately:

$$P = 4{\cdot}865\, H \sqrt[4]{H}\, e^{\frac{\pi}{2} + n\pi} = 23{\cdot}30\, H \sqrt[4]{H}\, e^{n\pi}$$

This is greater than the value corresponding to $x = 0$, which for any $\gamma_1 b$ is:

$$P = 4{\cdot}865\, H \sqrt[4]{H}\, \frac{Cos\, 2\gamma_1 b + cos\, 2\gamma_1 b}{Sin\, 2\gamma_1 b + sin\, 2\gamma_1 b} \tag{43}$$

and for $2\gamma_1 b$ sufficiently great:

$$P = 4{\cdot}865\, H \sqrt[4]{H} \qquad (44)$$

Contrary to what was necessary in the case of the circular ice sheet lest G should be ∞, we suppose here ρ to be naught, as it simplifies the formulas without materially altering the results.

By means of formulas (37), (39), (41), (42), (43) and (44), the following table has been prepared:

TABLE II.—VALUES OF p IN POUNDS PER SQUARE FOOT AND P IN POUNDS PER LINEAL FOOT.

$2b$ (in ft.)		10		100			$\sqrt{\text{1,000}}$		
	γ_1	p	P	p		P	p		P
H ($=0$ or h) in inch.	$\frac{1}{27{\cdot}5\,H^{\frac{3}{4}}}$	$0{\cdot}944\,H^{\frac{1}{4}}\,\frac{\cos 2\gamma_1 b + \cos 2\gamma_1 b}{\sin \gamma_1 b . \sin \gamma_1 b}$	$4{\cdot}865\,H^{\frac{1}{4}}\,\frac{\cos 2\gamma_1 b + \cos 2\gamma_1 b}{\sin 2\gamma_1 b + \sin 2\gamma_1 b}$	x			$\frac{b-x}{\frac{0{\cdot}7854}{\gamma_1}}$	$0{\cdot}271\,H^{\frac{1}{4}}$	$4{\cdot}865\,H^{\frac{1}{4}}$
1	0·0364	2·65	13·38	25	0·25	4·77	22	0·27	4·86
2	0·0216	10·65	53·63	0	0·21	8·69	36	0·38	11·57
3	0·0160	23·74	120·06	0	0·30	14·50	49	0·47	19·20
4	0·0129	42·16	213·21	0	0·53	23·26	61	0·54	27·52
5	0·0109	66·37	333·64	0	0·70	34·93	72	0·61	36·36
6	0·0095	95·44	480·46	0	0·99	49·40	83	0·66	45·67
7	0·0085	129·50	651·95	0	1·32	66·30	92	0·72	55·40
8	0·0076	171·37	861·53	0	1·74	87·08	103	0·77	65·45
9	0·0070	215·44	1082·99	0	2·17	109·19	112	0·81	75·82
10	0·0065	262·07	1332·91	0	2·65	133·88	121	0·86	86·48
11	0·0060	323·79	1625·77	0	3·25	163·11	131	0·90	97·43
12	0·0056	388·70	1938·39	0	3·90	194·67	140	0·94	108·64

For small values of H both p and P corresponding to $2b = 100'$ are smaller than for wider spans; and for a 100 feet

span p is smaller for $H = 2$ than for $H = 1$. This seems at first sight absurd, but it is a consequence of our assumptions. The ice sheet with the wider span can, with the same curvature at the banks, better take advantage of the support of the water. And the thin sheet can bend down with a sharper curvature than the thicker ice; for the thinner it is, the less the fiber strain for the same curvature.

A comparison of the two tables reveals a radically different build of the formulas, as was to be expected, inasmuch as in the lake, the curvature is synclastic or anticlastic, in the canal cylindrical. P, for the lake, is the weight distributed over a circular area of radius 2 feet; for the canal it is the load per lineal foot acting over the whole length at the center of the canal. A comparison is, therefore, hardly possible; even taken for a length of 4 feet, it is considerably less for the canal than for the lake, as should be expected. The uniformly distributed load, p, is, on the contrary, greater for the canal than for the lake; the ice can bend down more readily to be supported by the water.

The ice here considered is pure, hard, glare ice. At temperatures above or a little below freezing point, its plasticity may make it yield to pressure and strains without becoming fractured.

ELECTRICAL SECTION.

Stated Meeting, Tuesday, October 22, 1895.

MR. CARL HERING, President, in the Chair.

SOME FORMULÆ FOR THE CALCULATION OF WIRES.

RETURN LOOP SYSTEM.

BY EDWIN R. KELLER, M.E.

It was formerly generally assumed that, by the return loop system of wiring, an absolute uniformity of potential at the lamps was attained. The incorrectness of this assumption was first pointed out by Mr. Osborn P. Loomis, in an article which appeared in the *Electrical Engineer*, about four

years ago. Mr. Loomis showed that the potential at the lamps was not constant, and stated that, while it was sufficiently so for all practical purposes, it was impossible to secure absolute uniformity.

The first part of Mr. Loomis' statement was evidently correct, but the other, viz.: that absolute uniformity could not be attained, was subsequently disproved by Mr. Clayton W. Pike, who demonstrated that, if, in connection with the ordinary return loop system (*Fig. 1*), additional wires be used, as in *Fig. 2*, or, if the gauge of wire be properly altered, absolute constancy of potential at the lamps could be secured.

Such an arrangement as that shown in *Fig. 2*, however, is of purely theoretical interest, and even the ordinary return

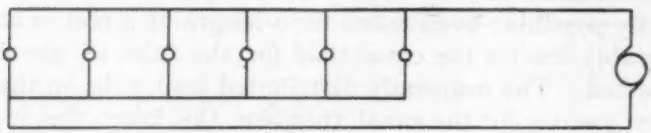

FIG. 1.

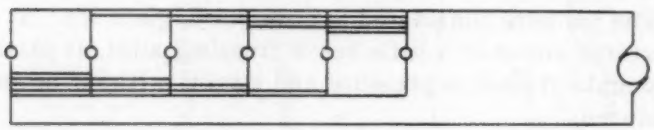

FIG. 2.

loop (*Fig. 1*) is rarely advantageous in practice, inasmuch as it involves the use of an extra length of wire, which (if conduit or moulding is used) would cost more than the saving effected in copper.

In the lighting of halls, lecture rooms, theatres, etc., it frequently occurs, however, that single lamps are distributed around the cornices, the whole circuit being controlled by a single switch. In this case architectural considerations usually require that the lamps be spaced evenly. The electrical problem is, then, how to wire in order to secure a minimum variation of potential at the lamps at the least expense for copper and conduit. The objection that an extra length of wire must be used in the return loop system no longer obtains, and it will be the object of this paper to determine

which of the methods ordinarily employed will give the most satisfactory results, and to present formulæ by which the wiring in such cases may readily be calculated.

There are three methods of wiring, which may be applied to cases of this kind: (*Fig. 3*).

In the first method we have simply the ordinary parallel system of distribution.

In the second, the loop closes on itself, so that the current is divided where it enters the circuit, one-half flowing in either direction.

The third, or return loop method, is similar to the first, except that the mains are run in opposite directions, so that the fall of potential is a maximum on the one, where it is a

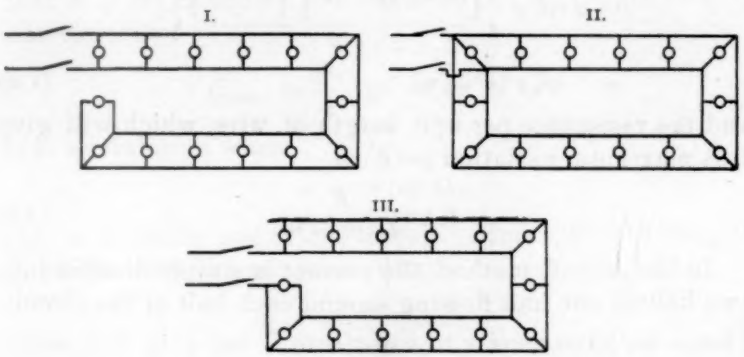

FIG. 3.

minimum on the other. At first sight, it would appear that the potential at all the lamps would be the same, and if this were the case, it would be sufficient to use a very small wire. That it is not, however, has already been shown by Mr. Loomis, and will appear presently from the formulæ:

Let c = current per lamp.

r = resistance per unit (foot) length of wire.

d = length of wire between any two lamps (single distance).

n = total number of lamps in the circuit.

E = the fall of potential.

In the first method the maximum difference in potential between any two lamps is evidently equal to the total drop

to the last lamp on the circuit. The drop from the first to the second lamp is

$$2\,rd.\,c\,(n-1);$$

from the second to the third,

$$2\,rd.\,c\,(n-2);$$

from the $(n-1)$th to the nth,

$$2\,rd.\,c.$$

Hence the total drop to the last lamp,

$$E = 2\,rd.\,c\left[(n-1)+(n-2)+\ .\ .\ .\ (1)\right];$$

$$= 2\,rd.\,c\left\{\frac{\left[(n-1)+1\right]\left[n-1\right]}{2}\right\};$$

$$= rd.\,c\,(n^2-n); \qquad (1\,a)$$

and the resistance per unit length of wire, which will give this maximum variation $(=E)$ is

$$r_1 = \frac{E}{dc\,(n^2-n)}. \qquad (1\,b)$$

In the second method the current is simply divided into two halves, one half flowing around each half of the circuit. Hence we have merely to substitute $\frac{n}{2}$ for n in the above formulæ.

$$E = \frac{rd.\,c}{4}(n^2-2n) \qquad (2\,a)$$

and

$$r_2 = \frac{4}{dc}\frac{E}{}\,(n^2-2n). \qquad (2\,b)$$

In the return loop system the drop to any lamp, say the xth from either end, is, plainly,

$$E_x = dr.\,c\left\{\left[(n-1)+(n-2)+\ .\ .\ .\ .\ (n-x+1)\right]\right.$$

$$\left.+\left[(n-1)+(n-2)+\ .\ .\ .\ .\ (x)\right]\right\};$$

$$= \frac{dr.c}{2}(n^2 + 2nx - 3n + 2x - 2x^2); \qquad (c)$$

from which it is evident that the drop is not independent of x, and hence different at every lamp. Differentiating,

$$\frac{dE_x}{dx} = 2n + 2 - 4x = 0$$

$$x = \frac{n+1}{2}$$

It is a maximum when

$$x = \frac{n+1}{2},$$

that is in the middle of the circuit. The maximum drop is, consequently,

$$E_{max.} = \frac{drc}{4}(3n^2 - 4n + 1) \qquad (d)$$

It is a minimum when

$$x = n \text{ (or } 1);$$

that is, at either end of the circuit. Hence, substituting in (c) we have for the minimum drop,

$$E_{min.} = \frac{drc}{2}(n^2 - n). \qquad (e)$$

This last equation might have been derived directly from $(1a)$, for, evidently, in the return loop system, the drop to the first or last lamp is equal to one-half the drop to the last lamp in the first system.

If now we subtract (e) from (d), we will obtain the greatest variation of potential between any two lamps in the circuit.

$$E = E_{max.} - E_{min.} = \frac{drc}{4}(n^2 - 2n + 1) \qquad (3a)$$

and

$$r_3 = \frac{4E}{dc(n^2 - 2n + 1)}. \qquad (3b)$$

We can now compare the relative economy of the three systems. The amounts of copper required are inversely

proportional to the resistances, and hence, if we call a_1, a_2 and a_3, respectively, the circular mills required in the three different systems to produce the same maximum variation in potential ($= E$), we have from ($1b$), ($2b$) and ($3b$):

$$a_1 : a_2 : a_3 = \frac{1}{r_1} : \frac{1}{r_2} : \frac{1}{r_3} = 4\,(n^2 - n) : (n^2 - 2n) : (n^2 - 2n + 1)$$

From this it appears that while the ordinary parallel system requires more than four times as much copper as the closed loop, there is very little difference between the closed loop and the return loop, though there is a slight advantage in favor of the second (closed loop) system. It must be remembered also that this comparison is made on the basis of a fixed maximum variation in potential between two lamps of the circuit, and not maximum total drop. From a consideration of the same total drop, the advantage in favor of the closed loop would be much greater. The amounts of copper would then be from ($1b$), ($2b$) and (d):

$$a_1 : a_2 : a_3 = 4\,(n^2 - n) : (n^2 - 2n) : (3n^2 - 4n + 1).$$

The following example will illustrate the use of the formulæ and show the results which would be attained in an actual practical case:

In a lecture room having 100 (110 v. 16 c. p.) lamps in five circuits, with a distance between the lamps of ten feet, and a maximum allowable variation of one volt between any two lamps, the resistance, by the ordinary parallel system, would be, from ($1b$):

$$r_1 = \frac{1}{10 \times \cdot 5\,(20 \times 20 - 20)} = \cdot 00053 \text{ ohms},$$

which corresponds to a No. 7 wire (B. & S. Gauge).

By the closed loop system it would be:

$$r_2 = \frac{4\,(20 \times 20 - 20)}{(20 \times 20 - 40)} \times \cdot 00053 = \cdot 00222,$$

which corresponds to a No. 13 wire.

And by the return loop system

$$r_3 = \frac{4\,(20 \times 20 - 20)}{(20 \times 20 - 40 \times 1)} \times \cdot 00053 = \cdot 00221,$$

which also corresponds to a No. 13 wire.

By the first two systems, however, the total drop would be but one volt, while by the return loop system the difference between the maximum and minimum would be equal to that amount. The drop to the first lamp would be from (*e*)

$$E_{\text{min.}} = \frac{10 \times \cdot00221 \times \cdot5}{2}(20 \times 20 - 20)$$

$$= 2\cdot09 \textit{ volts},$$

and the drop to the middle of the circuit from (*d*)

$$E_{\text{max.}} = \frac{10 \times \cdot00221 \times \cdot5}{4}(3 \times 20 \times 20 - 4 \times 20 + 1)$$

$$= 3\cdot09 \textit{ volts}.$$

The same size wire in the second system gives a total maximum drop of one volt, and in the first system from (1*a*):

$$E = 10 \times \cdot00221 \times \cdot5\ (20 \times 20 - 20)$$

$$= 4\cdot18 \textit{ volts}.$$

In other words, for the same maximum variation in potential in the three systems, the weights of copper would be, roughly:

$$208 : 52 : 52;$$

and the total drop

$$1 : 1 : 3\cdot09;$$

while for the same weights of copper, the maximum variations in potential would be:

$$4\cdot18 : 1 : 1;$$

and the total drop

$$4\cdot18 : 1 : 3\cdot09.$$

SOME NOTES ON ELECTRIC RAILWAY TESTS.*

Prof. Herman S. Hering presented to the Section "Some Notes on Electric Railway Tests," of which the following is an abstract, and which should prove of great value, and well worth the great amount of time and labor spent upon the collection of the data on which they are based.

The first point discussed was the importance of intelligent management of the controller by the motorman in order to obtain the best results. Starting too suddenly must be avoided, not only out of consideration for the comfort of passengers, but also because the mechanical strains would be serious and the motors would be working inefficiently. On the other hand, the cars must not be started too slowly, for the reason that the motors would work at a point of low efficiency, and also because the time of the trip would be lengthened. The cars should be allowed to "drift" as much as possible, so as to avoid waste of energy when brakes are applied.

Experimental trips, under careful observation, made with an expert and a non-expert motorman, under similar conditions, demonstrated that the expert accomplished the trip with the same number of stops and passengers as the non-expert, and with a saving in energy used of from 15 to 25 per cent. On a ten-mile road running fifteen cars, the saving from this source would amount to about $810.

The speaker next discussed the question of the loss of energy due to the sparking of the trolley wheel. This was found to be, for old wheels, as much as 250 watts; and for new wheels, 60 watts. Insufficient tension on the spring was said to be responsible, generally, for this loss, which may be obviated by careful inspection and adjustment of the springs.

The loss from imperfect contact between rail and wheels

*Abstract of remarks made at the stated meeting of the Electrical Section of the Franklin Institute, held September 24, 1895.

was also determined, and, in the case of a track slightly sanded, was found to be about ·04 horse-power.

RECORDING AMMETER AND VOLTMETER.

At the same meeting, Professor Hering also described a "Recording Ammeter and Voltmeter," devised by him, for use in the tests above referred to.

As described by the speaker—and illustrated by sketches on the blackboard—this instrument consists of a Weston apparatus, in which the needle moves over a sharp metallic edge, with a strip of paper sensitised with calcium chloride between the needle and the sharp edge of the metal. One terminal of a small induction coil is connected to the needle, the other to the metallic edge, and the record is made by the spark in its passage through the paper from one to the other. The speaker exhibited curves taken with the instrument.

THE JOHNSTON RAIL-BOND.

At the same meeting, Mr. A. Langstaff Johnston exhibited several specimens of his rail-bond, which had been removed from the road-bed of the Hestonville Passenger Railway Company, Philadelphia. Mr. Johnston stated that the rails to which these bonds had been attached had been down for two years. The contacts between the iron of the rail and the metal of the bond, on the specimens shown, appeared bright and clean. From the experience with the bond gained on the line of this railway, Mr. Johnston stated that soldering the bond to the iron, which was originally done, had been found to be unnecessary.

CHEMICAL SECTION.

Stated Meeting of October 15, 1895.

DR. WM. C. DAY, President, in the Chair.

CARBIDES OF IRON.

BY F. LYNWOOD GARRISON.

In reviewing the history of the metallurgy of iron and steel, we find that ever since the recognition of the important role which carbon plays in the economy of this important industry, great efforts have been made to explain the phenomena, presumably due to carbon, which accompany certain metallurgical operations. The mere fact that carbon was known to exist in the metal in two distinct forms, graphitic and combined (the latter so-called for want of a more scientific definition), was not sufficient to explain to the inquiring mind such changes of molecular structure as take place in the cementation furnace; and that this particular problem is perhaps no nearer solution to-day than thirty years ago, is probably due, in great measure, to the fact that the process as a commercial operation has long since fallen into disuse. It has, of late, however, cropped up in a somewhat different form in the methods of face-hardening armor-plate by the addition of carbon, and possibly of chromium.

Although, within recent years, patents have been granted for increasing the combined carbon, and thus imparting additional hardness to articles of steel, as long ago as 1830, Karsten, in his researches upon the solvent action of acids upon iron and steel, observed a carbon compound which was evidently not graphite, and which must, consequently, be considered under the equivocal head of combined carbon. He did not succeed either in preparing or separating such a carbon compound having a definite chemical composition, but his observations led him to believe that carbon united with iron in such proportions that chemical union was effected, and that the

resulting body would probably correspond to the formula Fe_3C.[1] Berthier[2] claimed to have obtained a definite monocarbide, FeC, by the action of iodine and bromine upon steel. His observations, however, were never confirmed, and Caron[3] vainly attempted to produce this carbide by a similar solvent action of bromine, or iodine. Hence, the latter chemist concluded that the carbide of Berthier was a mixture of carbon and iron, in which the iron was mechanically protected from solvent action by the carbon. Berzelius[4] claimed to have obtained the carbide, FeC_2, by the distillation of ferrocyanide of ammonia; and another carbide, Fe_2C_3, by treating pure Prussian-blue in the same manner. Whether these residues were actual combinations of carbon and iron, or only mixtures of carbon and iron slightly carbonised, is doubtful. Percy[5] appears to regard their acceptance as definite compounds with reservation.

The first investigators to isolate a definite carbide from iron, were Müller and Abel, who, though working independently, appear to have obtained similar results.

Müller, like Karsten, obtained the carbide by the action of dilute sulphuric acid upon Bessemer steel, the resulting residue being pyrophoric, and containing from 6·01 to 7·38 per cent. of carbon. Hence he deduces the formula Fe_3C. Müller[6] remarks that, by the solvent action of the acid, a very large quantity of the total carbon must have been converted into hydrocarbons, since, by calculation, the carbon of the carbide is only from 20 to 50 per cent. of the total amount in the steel.

Abel obtained Fe_3C, by the action of a solution of potassium bichromate and sulphuric acid, containing just sufficient acid to dissolve the iron, since the amount of free sulphuric acid present greatly affects the yield of carbide. The carbide obtained by Abel[7] from several varieties of

[1] *Manuel de la Metallurgie du Fer* (Metz, 1830), Vol. 1. p. 173.
[2] *Ann. des Mines* (3), **3**, 229.
[3] *Comptes Rendus* **56**, 44; *Percy, Iron and Steel* (1864), p. 122.
[4] *Traité de Chimie* (1831), p. 270; *Percy, Iron and Steel* (1864), 122.
[5] *Metallurgy of Iron and Steel*, p. 123.
[6] *Zeitschrift des Vereins Deutscher Ingenieure*, **22**, 385.
[7] *Proceedings Inst. Mech. Engs.* (1885), 30–57.

iron, had a somewhat variable composition, as shown in the following analyses:

	H_2O. Per Cent.	C. Per Cent.	Fe. Per Cent.
Cold-rolled steel	0·93	6·92	92·77
Annealed steel	1·32	7·04	91·80
Tempered steel	2·28	7·23	89·92
Cold-rolled tempered steel	2·09	7·12	90·87

Less than 0.93 per cent. of the water is probably present as mechanically retained moisture, the greater part being a constituent of a carbo-hydrate resulting from the decomposition of the carbide, since this increase in the proportion of water is attended by an increase of carbon and a decrease of iron. The specific gravities of the carbide are, respectively, as follows:

From cold-rolled steel	6·9
From annealed-rolled steel	7·2

Abel[8] concludes that, at least in the unhardened steel, the carbide exists entirely as Fe_3C. Osmond and Werth[9], by submitting bars of steel to electrolysis in hydrochloric acid, and examining the residue microscopically and chemically, identified the carbide, Fe_3C, observed by Abel. They obtained it in brilliant magnetic scales or plates, and also observed that when a bar of steel is heated to redness it contains, besides carbides of iron, free carbon ("carbon libre"), the proportion of the latter increasing with increase of temperature.

The observations of Arnold and Read[10] show that a readily decomposable sub-carbide of iron exists, the iron of which is dissolved by the solvent, whilst the carbide escapes in the form of hydrocarbons. As a result of their extensive investigations, they arrive at the following conclusions:

(1) The "normal carbide"[11] exists in two forms of identical composition; (*a*) a diffused carbide scattered in microscopic granules, or very small plates, yielding on isolation a

[8] *Ibid.*

[9] *Ann. des Mines* (8), **8**, 19 *et seq.*

[10] *Jour. Chem. Soc.* (Trans.), **65**, 788.

[11] They use the term "normal steel" to designate a steel heated to 1,050° C. and cooled in air. The normal carbide is, of course, the carbide from such a steel,—F. L. G.

grayish-black powder; (*b*) a crystalline carbide arranged in comparatively large distinct plates, in well annealed steel. These crystals are almost chemically pure Fe_3C, and are identical with the microscopical laminæ of Sorby's "pearly constituent."

(2) The percentage of total carbon obtained as carbide is greater in hard than in mild steel.

Iron containing	1	per cent. C.,	92	per cent. as carbide—	loss	8	per cent.
"	"	0·5	"	"	87	"	"	"	13	"
"	"	0·25	"	"	74	"	"	"	26	"

This loss does not appear to be due to decomposition, but rather to the presence of an unstable sub-carbide of iron existing to the extent of 25 per cent. of the total carbon in the case of mild steel, and capable also of existing to a like amount in hard steel after it has been heated for some time at a white heat. The loss appears to be the same in well annealed, as in "normal steel," hence it cannot be due, as supposed by Ledebur,[12] to the presence of hardening carbon.

(3) The carbon in hardened steel exists chiefly in solution, or as a feebly combined and extremely attenuated carbide, leaving, on isolation, a residue consisting mainly of a hydrate of carbon mixed to a slight extent with normal carbide of iron. Whether the large loss of carbon (about 50 per cent. of the total) occurring during the decomposition of the hardened steel, is due to the presence of a considerable amount of sub-carbide, or to the evolved hydrocarbons, formed by the action of nascent hydrogen on finely divided, or feebly combined, carbon, there is no conclusive evidence to show, although the amount of evolved gas from hardened steel does not perceptibly exceed that from unhardened samples.

(4) In steel high in manganese (1·73 per cent.), a portion of the iron in the carbide may be replaced by manganese. The double carbide $Fe_7(Mn)C_3$, thus formed, is less stable than that of iron alone, especially in "normal steels." This double carbide is described as a uniform light-gray metallic powder.

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[12] *Jour. Iron and Steel Inst.*, No. 2, 1893, p. 53.

In connection with this observation upon the probable existence of a double carbide of iron and manganese, the researches of Troost and Hautefeuille are of interest. They found that, in uniting, manganese and carbon disengaged a great deal of heat and formed a stable compound Mn_3C, this evolution of heat being characteristic of all combinations of iron, manganese and carbon. Hence, all ferro-manganese alloys may be regarded as true chemical combinations. The amount of heat disengaged when these carbides were treated with bi-chloride of mercury appeared to vary according to the amount of carbon present.[13]

It is evident from this brief summary of the more important investigations upon the character of the simple carbides of iron, that we have to deal with a most complex chemical and metallurgical problem; and, although it may be urged that such investigations have yielded little of practical value, it must be manifest to anyone familiar with the subject that they may ultimately give us some definite and tangible knowledge of the chemical and physical properties of the various compounds, solids and gases which are of such vital importance in the constitution of the several varieties of iron which we have in commerce.

The futility of attempting to determine the character of some of these solid constituent compounds by a mere optical examination, without isolation and chemical analysis, must be evident, as witness the fact that Sorby's "pearly constituent." or "pearlite," has been proven by Arnold and Read to be simply the carbide, Fe_3C, long before observed and described. As everyone must have observed who has done much microscopical work with various opaque objects, reflected light, which must of necessity be used for illumination, is apt to play one tricks, and what, in one case, might appear to the eye as a distinct body, in another, may appear to be something quite different. As I have previously pointed out,[14] we have not in iron, as we have in rocks, a body composed of pre-determined compounds. To determine

[13] *Comptes Rendus* **80**, 964.

[14] *Jour. Iron and Steel Inst.*, No. 1, 1895, p. 251.

the structure of a rock, the student has to familiarise himself with the characteristics of the minerals of which it is constituted. Since mineralogy may now be considered an exact science, it is a comparatively easy matter to master its essential details. In the case of iron, however, we practically know little or nothing of its constituent compounds; a chemical analysis exhibiting its composition, as so much iron, carbon, silicon, phosphorus, etc., gives us no more idea of its actual composition than would a similar analysis of a rock.

In both cases we obtain the ultimate composition of the body; that is, we would know with a fair degree of accuracy the total amounts of the respective elements present, but in no case does such an analysis give us more than a vague idea of the manner in which these elements are united amongst themselves. Following this line of reasoning, it must be evident that the only rational solution of the problem lies in first isolating, and then studying each one of the several constituent compounds (not elements) existin the iron, just as has been done in mineralogy and lithology.

Apparently, in accordance with this plan, Mr. James S. de Benneville, of Philadelphia, has recently devoted himself to the study of certain triple, or ternary, iron alloys, and with the result that he has discovered at least two new compounds, which are undoubtedly iron carbides.[15]

These carbides were obtained from specially prepared alloys of iron, chromium and tungsten, and of iron, chromium and molybdenum, respectively, by the action of dilute nitric acid (1·20 sp. gr.). The chromium-tungsten and the chromium-molybdenum were united in the ratio of 5 : 1. The carbides yielded on analysis, results corresponding, respectively, to the formula $Fe_7(CrW)_6C_4$ and $Fe_7(CrMo)_8C_4$. They are distinctly crystalline bodies (hexagonal prisms),

[15] *Jour. Iron and Steel Inst.*, No. 1, 1895, pp. 202–253. It is but proper that I should state that this parallelism between lithology and iron metallurgy, is an idea of my own, for which Mr. de Benneville must not be held responsible; in fact, I do not know that he approves of it, since I have not heard him express his opinion upon the subject.—F. L. G.

and are similar in appearance. The crystals of chromium-tungsten are from $\frac{3}{100}$ to $\frac{4}{100}$ of an inch in length and $\frac{3}{1000}$ of an inch in diameter, and when heaped in masses have a decided yellowish metallic tint. The chromium-molybdenum crystals are of the same length, $\frac{5}{1000}$ of an inch in diameter, and when heaped have a dark steely-gray lustre. The specific gravity was 12·8 for the tungsten, and 7·473 for the molybdenum alloy; both were very feebly magnetic.

It is of interest to note in connection with this subject, that recently, Behrens and Van Linge[16] obtained, by treating ferro-chromium with fuming hydrochloric acid, what they describe as minute, rod-shaped (stäbchen), crystals, from 3 to 4 millimeters ($\frac{3}{25}$ to $\frac{4}{25}$ of an inch nearly) in length, non-magnetic; hardness 7·5. The chemical composition of these crystals varied with the ferro-chromium from which they were obtained; ferro-chromium with 13·8 per cent. chromium, 81 per cent. iron and 5·5 carbon, giving the compound $Cr_2Fe_7C_3$; whereas, with 50 per cent. chromium, the composition was approximately Cr_2FeC_2. The first compound they regarded as Fe_3C, in which iron is replaced by chromium; in the second, the increased carbon percentage may be considered as due to the high temperature necessary to produce the ferro-chromium. They ascribe the extreme hardness to carbon rather than to chromium, as much chromium remained in the part of the alloy which was soft. Chromium appears to facilitate the formation of a carbide, whose characteristics, even in pure carbon steels, are great hardness and chemical stability.

These statements are of interest, as being confirmatory of opinions, which I have on several occasions expressed, that, of itself, chromium does not harden steel.[17]

Within the past few weeks, Mr. de Benneville has obtained a similar crystalline substance from a ferro-chromium containing about 20 per cent. chromium. He has not yet determined its chemical composition, but it is presumably also a carbide. I have examined the crystals, and find

[16] *Zeitschr. Anal. Chem.*, **83**, 513–533.

[17] *Jour. Iron and Steel Inst.*, No. 2, 1892, p. 151; *U. S. Geological Survey, Mineral Resources*, 1894, p. —.

them to be apparently hexagonal in type, but not so fully developed as those from the ternary alloys. They are also more minute, averaging about $\frac{3}{1000}$ of an inch in length, and $\frac{5}{10000}$ of an inch in diameter; being feebly magnetic, dark gray in color, and with steely lustre.

ADDENDUM.

An interesting illustration of the strong affinity between iron and carbon is afforded by the presence of a natural iron carbide in certain meteoric bodies. Cohen and Weinschenk[18] first observed this compound in the meteoric iron from Magura, Hungary, and Wichita County, Tex. It appeared in the form of crystals, "arranged parallel to an octahedral face;" was found to contain from 5·1 to 6·4 per cent. carbon, and from 1·5 to 3 per cent. nickel; hence should be regarded as a double carbide of iron and nickel; or, if the cobalt be considered, a triple carbide. These investigators named this compound Cohenite, and claimed that it corresponded to the compound Fe_3C, obtained from cast iron. From their analyses they derived the formulæ $(Fe,Ni,Co)_3C$ and $(Fe,Ni,Co)_4C$.

Derby[19] obtained quite a considerable amount of this carbide (Cohenite) from the Cañon Diablo, Arizona, meteorite. His analyses of two samples are as follows:[20]

	I. *Per Cent.*	*II.* *Per Cent.*
Fe	92·88	91·67
Ni + Co	1·33	2·43
P	0·48	0·09
C	5·33	6·07

Previous to the investigations of Derby, Koenig[21] claimed to have discovered diamonds and "amorphous carbon" in the Cañon Diablo meteorite. According to Derby, however, "nothing resembling that substance (diamond), or any other form of free carbon, could be detected."[22] This observation of Koe-

[18] *Ann. Nat. Hist. Mus. Wein.*, **6**, 131; *Dana's Mineralogy*, 1893, p. 1038.

[19] *Am. Jour. Sci.* (3), **49**, 101.

[20] *Loc. cit.*, 106.

[21] *Am. Jour. Sci.* (3), **42**, 415.

[22] *Loc. cit.*, 108.

nig's evidently lacks confirmation, and cannot be accepted as proven. Graphitic carbon was observed, years ago, in certain meteoric irons.[23] Now, as we have seen, definite carbides are formed; hence, it will be noted that, in this respect, the meteoric metal is analogous to the iron of commerce. The existence of carbon in the form of diamond in the meteoric metal is probably as unlikely as in the ordinary forms of iron; the mere fact that the temperature of the meteoric mass, when coming in contact with the atmosphere of the earth, becomes enormously increased, would be sufficient to dispel the supposition, since we know, from the experiments of Hempel[24] and Roberts-Austen[25] that carbon in the form of diamond unites more readily with iron at a red heat than either graphitic or amorphous carbon; consequently, admitting the carbon in the meteoric metal to be in the diamond form before the metal came in contact with the atmosphere, and before it was subjected to the resulting high temperature, we would naturally suppose, from our knowledge of the results obtained by these experiments, that the carbon would be changed from the diamond form, either by union with the iron as a carbide, or to the form of graphite.

NOTES AND COMMENTS.*

THE FUTURE OF THE ELECTRIC TELEGRAPH.

In the October impression of *The Engineering Magazine* appears an exceedingly interesting and suggestive paper from the pen of Mr. Patrick B. Delany, an acknowledged authority in this field, on the future of the electric telegraph, in which the author sets forth, in a most instructive way, the possibilities of an enormous extension of the use of the telegraph, and, incidentally, presents a strong argument in favor of Government ownership of the telegraphic systems.

We present in the following an abstract of this important paper, embodying the salient points of Mr. Delany's argument, and refer our readers to the original source for the paper in full:

[23] *Am. Jour. Sci.* (2), **8**, 439; *ibid.* (2), **19**, 157.
[24] *Ber. der deutsch-chem. Ges.*, **18**, 998.
[25] *Jour. Iron and Steel Inst.*, No. 1, 1890, p. 81.
* From the Secretary's monthly reports.

"The future of the telegraph," says Mr. Delany, "will depend largely on the telegraph of the future. The telegraph of the present is, in its main features, the telegraph of the past; and, if it is to continue without material change, it is an easy matter to figure out its future, upon the basis of so many feet of wire for each inhabitant.

"We have now about 1,250,000 miles of wire to 65,000,000 people; but the probabilities are that, when we reach Mr. Gladstone's 400,000,000 mark, there will not be as many miles of telegraph wire as there are at present.

"It does not require much foresight to realize that the final destiny of the telegraph is to carry all correspondence of any urgency, and that the present method of hand-working, with its slow speed and multiplicity of wires, will give place to automatic or machine transmission, high speed, and fewer wires.

"At present, owing to the expense, the telegraph is used only in cases of urgency, commercial or social. If a despatch could be sent as cheaply as a letter, the mails would dwindle to a mere miniature of their present bulk. In the commercial aspect, it is simply a question of time against cost. Where 'time is money,' the telegraph claims its tolls. But there are degrees of urgency below the extreme which demand quicker communication than that afforded by the railway train; and the telegraph of the future will recognize these degrees of urgency, and provide for them. With the exception of the half-rate night messages, telegraph companies have never attempted to differentiate their facilities. Messages, as a general rule, have been forwarded in the order of filing. In a case of life or death, no one can acquire, by offering double, or a hundred-fold, the usual rate for a telegram, the right to insist on precedence. It is optional with the company to push the message ahead of comparatively unimportant traffic, or transmit it in its turn.

"There are fast trains, and fast steamers at premium rates, fast freights, and extra-delivery letters; but, except in the case of the night message, a telegram is a telegram, and haste goes only by favor. Common sense surely points to a change in this way of carrying on telegraphy. The Morse key, relay and sounder, with hand transmission, are, and will probably for a long time remain, indispensable for a certain class of business, *i. e.*, broker messages, train orders, and other despatches requiring instantaneous transmission. No automatic system requiring preliminary composing or preparation of messages will ever meet the requirements of the exchanges, between which transactions involving great amounts are made in a few seconds. * * *

"It is pretty well settled that the telegraph companies cannot go on increasing the number of wires. They themselves admit that, in future, increase of facilities will have to come either through automatic working or through a further multiplication of circuits derivable from a single wire, and of the latter there is little hope.

"The British post-Office recognised the inadequacy of hand telegraphy more than twenty years ago, and put in operation the Wheatstone machine system. Beginning with a speed of about fifty words per minute, the telegraph department, with praiseworthy persistency in the direction of higher speed, has gradually improved the system, until now it is carrying an enormous amount of traffic at speeds ranging from 100 to 400 words per minute, accord-

ing to distance and the character of the conductor. The system is also worked duplex, but at speeds less than double the simplex speeds.

"The Wheatstone system was introduced into this country about ten years ago, and, although it has not been extended as rapidly as might have been expected, it is firmly established on several of the most important routes, notably from New York to Chicago. Over this circuit 75 words per minute duplexed, or 150 words in all, are obtained. An automatic repeater is used at Buffalo, as through working is not practicable over the present wires.

"Now, while the Wheatstone system is a great advantage over the hand method for heavy traffic, it can never, in the nature of things, be the telegraph of the future—that is, if the great bulk of correspondence is to be carried by telegraph. * * *

"Giving the Morse and Wheatstone systems full credit, it is my opinion that the system for carrying the mass of correspondence now carried by mail will be one of employing automatic transmission, and chemically prepared paper for reception of signals—a system having no electro-magnets, no armatures or movable parts, no springs or contacts to adjust, and no inertia to overcome, and one that is not thrown out of adjustment by slight changes of the circuit. The chemical plan of recording is based upon electrolysis. The saturated strip of paper forms a part of the circuit, and its sensitiveness for speed is at least twenty times greater than that of any electro-magnetic recorder.

"Davy is credited with the discovery that the passage of an electric current through paper moistened with certain chemicals would leave a mark in the track of the scraping finger, under which the paper ribbon was drawn. Alexander Bain was the first to use this discovery for recording telegraph signals. His automatic system of about forty years ago met with some success, but it had numerous defects, both mechanical and electrical. The perforating machine for preparing the message for transmission was crude, slow, and unreliable. 'Tailing,' or running together of the signals, making it difficult to separate the dots from the dashes, was the chief electrical difficulty.

"During the past twenty-five years chemical telegraphy has at different times engaged the attention of numerous able inventors, and considerable progress has been made towards overcoming the difficulties in the way of complete success. * * *

"Recent improvements in the perforating machine, transmitter, and receiving instrument, for automatic chemical telegraphy, have at last brought this ideal plan of rapid communication to a degree of perfection which cannot fail to bring about sweeping changes in transmission of correspondence in general. Between New York and Philadelphia, over a copper wire weighing 300 pounds to the mile, 3,000 words per minute can be recorded perfectly; and, with a copper wire weighing 850 pounds to the mile, 1,000 words per minute can be carried from New York to Chicago. It is between such large centres and over such long distances that the importance of such an achievement can be appreciated. The field for such a system lies between the present telegraph rate of, for example, 40 cents for

10 words from New York to Chicago, and the letter by rail, occupying nearly 30 hours, for 2 cents. At a speed of 1,000 words per minute over one wire, it is estimated that a 50-word message can be perforated in New York, transmitted automatically, typewritten, and dropped in the post-office in Chicago at an actual labor cost of 3 cents, to which the cost of the stamp must be added. Two wires of the character named, worked to their highest capacity, would carry all the letters now exchanged between New York and Chicago (provided their average length is not more than 50 words), and all the messages handled by the telegraph companies as well.

"When it is once proven practicable to deliver 1,000 words per minute in plain Morse characters over a circuit 1,000 miles in length, all prejudices hedging about old systems and methods of handling business should be swept aside. A perforator and a type-writer will, in effect, be a sending operator, and a receiving operator, and about forty will be employed at each end of a single wire. * * *

"As late as twenty years ago nearly every business man wrote his own letters, and very bad chirography jogged along by mail train at 20 miles an hour. Now, probably over 90 per cent. of the business letters are dictated to stenographers, and plain typewriter print speeds along at 40 miles an hour. The letter of the future will be dictated to a stenographer, who, instead of typewriting it, will perforate it on a paper tape. This tape will be sent to the telegraph office, where it will be put through the automatic transmitting machine, and in a second or two it will be at its destination. The receiving tape will be delivered direct, and the plain Morse characters will be translated on the type-writing machine by the correspondent's stenographer. Commercial houses having a large business will do their own perforating and translating, thus securing important reductions from the regular tolls. For them the telegraph company will be simply a carrier, having nothing to do with their correspondence but putting it through the machine. Nor will such messages be read by any of the company's employees, any more than open letters are now read by postal clerks. This will practically render all correspondence secret, as the perforated slip may be withdrawn as soon as it has been used. The contents will not be forced upon the notice of the telegraph operator as it present. Newspapers, railway companies, or other large corporations which now frequently have to resort to ciphers and codes to prevent 'leakage,' will welcome this privilege of protecting their secrets. A few weeks' practice is all that is necessary for learning to read the Morse characters with great facility from the paper tape, and proficiency on the perforating machine may be reached in the same time, so that to the already varied accomplishments of the typewriter will be added perforation and translation of telegraphic correspondence. Translation from Morse characters will be easier than from stenographic notes, with none of the elements of doubt attaching to the latter. * * *

"Speculation as to the future of the electric telegraph would be within extremely narrow bounds if the question of Government control were not considered. It may be somewhat remote, but it is hard to avoid the conclusion that the Government will not always draw the line as to the vehicles to be

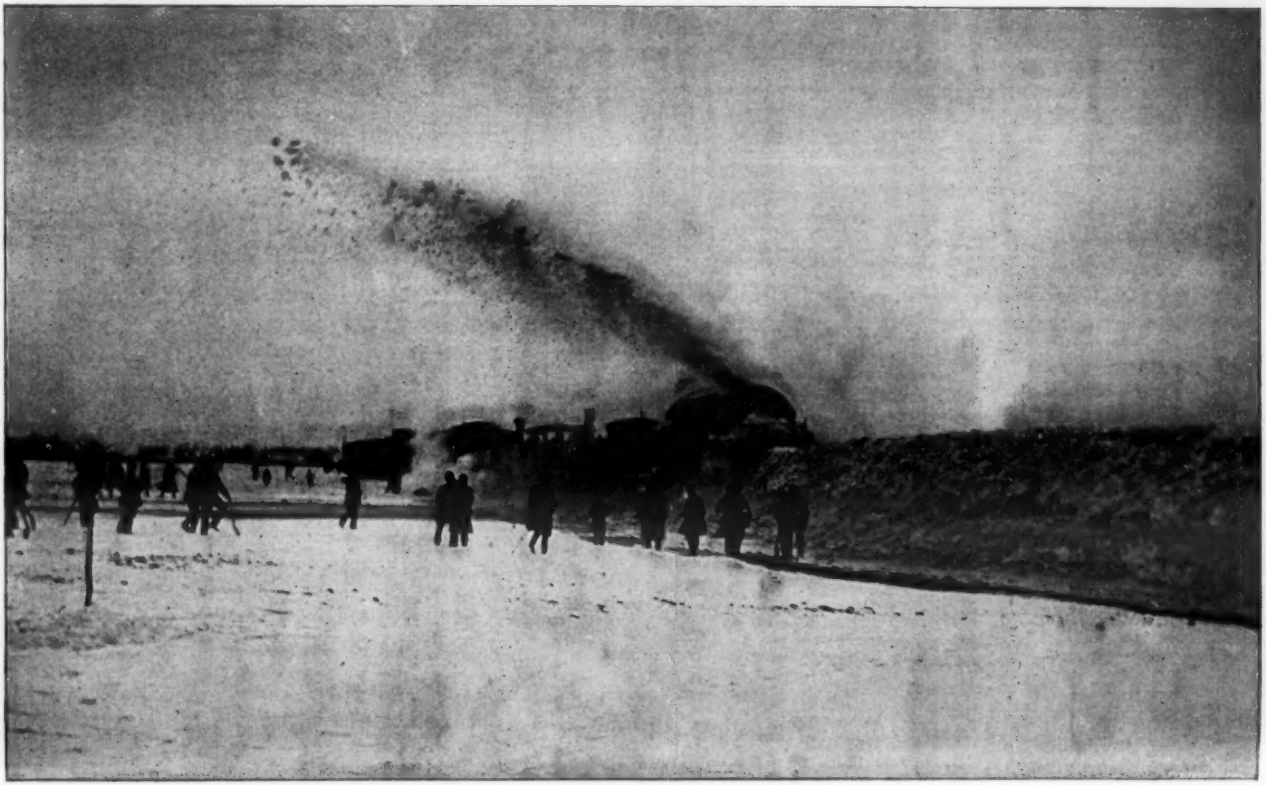
employed for carrying its mail. It now uses over 3,000 railway cars on 150,000 miles of road, and keeps 6,000 clerks on the move, traveling in crews 140,000,000 miles a year, during which time 9,000,000,000 pieces of mail matter are handled. About 300 mail cars are wrecked, a dozen clerks killed, and 150 injured during the same period. The total expense of the postal service is about $75,000,000 per annum, and the department is not far from self-sustaining. How can so vast a system ignore the difference between railway and electrical speeds? A car travels 40 miles an hour, a current 200,000 miles a second. The automatic chemical telegraph will send a message of 16 words from New York to Chicago every second, and 50 words—about the average of a business letter—in 3 seconds. If time be reckoned as the basis of value for correspondence, which will appeal most to the business man—a letter occupying 24 hours in covering 1,000 miles for 2 cents, or a telegram going the same distance in 3 seconds for 15 cents? Would not a very large proportion of business communications warrant the extra 13 cents? * * *

"Neither the Constitution nor any Act of Congress places limit or restriction on the mode of mail-carrying. The giant proportions and rapidly increasing power of telegraph interests of late years, coupled with the difficulties presented by the political aspect of the case, doubtless account for the fact that to-day the United States is the only country that does not control its telegraphs. Other Governments took them over in comparative infancy, when it was an easy thing to do, and telegraphy has thus become engrafted into their general schemes of communication. The use of the telegraph in many countries of prominence is much more general than in America, notwithstanding the fact that nearly all the improvements—notably Hughes' printer, the duplex, quadruplex and synchronous multiplex systems in their practicability—came from America. The British Post-Office, without prejudice or jealousy, took all these in their turn, and concurrently developed their own Wheatstone system, until to-day, for reliability, accuracy and uniformity of time, its telegraph service is unequaled.

"The British telegraph has not paid its way. It almost reached the maintenance point a few years ago, but the telephone inroads on its business became too great. The deficit is attributed mainly, however, to the enormous amount of press reports carried at very low rates. At night, the first charge of a shilling on a 100-word message having been paid, the message may be duplicated as many times as desired to any part of the United Kingdom for 4 cents.

"In foreign countries, as with ourselves, popular rates have not been available, owing to slow methods of operating; but, now that automatic working is supplanting the hand system, important changes may be looked for. Already Italy, having introduced the Wheatstone system, is about to make the experiment of 5-cent telegrams.

"It seems inevitable that, sooner or later, in this country, the Government will use the telegraph, either in a monopolistic or a competitive way. It cannot go on restricting the postal service to hauling of actual paper by rail. Among other of its beneficent aims, its mission is to place its people in com-



TEST OF AMERICAN ROTARY SNOW-PLOWS ON THE PRUSSIAN MILITARY RAILWAY, AT MAHLOW.

munication by the quickest means at the lowest cost, and for this purpose the telegraph alone will answer. There can be no more striking example of the public desire for quick facilities of communication than is shown in the avidity with which they have taken advantage of the quick-delivery system instituted by the post-office a few years ago. Every such letter is an evidence that the writer is willing to pay 10 cents in order to expedite the delivery of his letter half an hour. If these letters could be telegraphed for, say, 15 cents, or 3 cents more than the ordinary and extra postage, no one can doubt that nearly all would go that way."

THE SCHEFFLER-KURTH ROTARY SNOW-SHOVEL.

At the stated meeting of September 18th, Dr. Robert Grimshaw made some remarks upon the introduction of American rotary snow-shovels in Europe, especially in Germany, illlustrating them on the screen by a photographic view taken on one of two trials made in the latter part of last winter, on the Prussian Military Railway at Mahlow, near Berlin. (See accompanying illustration.)

The speaker explained that the use of rotary snow-shovels in Central Europe had not been demanded at all for commercial reasons, nor (by reason of the usually moderate snowfall) for military purposes. But the severe snows of last winter, blockading so thoroughly so many of the railways of Europe, caused apprehension in military circles, lest future snowfalls should prevent the rapid transportation of troops and materials of war from one strategic point to another; hence, the German Government looked into the matter for military rather than for commercial reasons.

It being found impossible to get any regular railway to make a trial of the Scheffler-Kurth shovel at its own cost, or even at the builders' expense, the use of a section of Government military railway (which is distinct in management and purpose from other regular governmental railways) was obtained and a snow-heap built thereon, 600 meters in length and from 2½ to 4½ meters high. To build this it was necessary to haul some twenty train-loads of snow from the streets of Berlin, in addition to what could be obtained in the neighborhood. The compacted mass as presented for removal by the shovel, was composed of partly-frozen slush, and had a specific gravity of 0·750. The results of the first test (made under conditions much more severe than ever met with in actual railway service) were but partially successful, by reason of the too rapid advance of the train, due to nervousness and inexperience of the engine-runners; but a second trial, two days later, with a snow-heap of similar compactness and height, and 1,000 meters in length, demonstrated most satisfactorily the superiority and efficiency of the American system of snow removal.

The machine tried on this occasion has a twin-cylinder, single-expansion, double-acting vertical engine of 800 horse-power, driving a shaft 10 inches in diameter, at the forward end of which is a rotary shovel 10 feet in diameter and having twelve blades fastened firmly to a pointed hub at the end of the shaft, and to a peripheral wrought-iron ring. Across this latter there is a

strong diametral breaker-bar, in advance of the blades, and serving to cut the snow when frozen, thus relieving the blades. This shovel rotates in an adjustable cylindrical boiler-iron case, open in front, and having in its periphery a side outlet, the position of which can be so changed by partial rotation of the case (effected through clutch-gearing, by the main engines) as to throw the snow in a continuous stream either to the right or to the left of the track, and at any desired angle from horizontal to vertical. This obviates the necessity of reversing the engine, as is done in most American rotary snow-shovels. In addition to its partial rotation, the case may be slightly raised at switches and crossings. The entire machinery is mounted in a specially constructed box-car. Steam for the twin engines is furnished by a spiral copper pipe from a locomotive directly coupled the to rear of the shovel-car; and the exhaust passes through a similar spiral pipe to the smoke-box of this locomotive. This latter could, if sufficiently powerful, have given the necessary advance to the shovel-car; although, on this occasion, a second locomotive was employed for pushing.

Two of these machines have been in successful operation for two winters on the Government railways in Hungary.

THE KÖPCKE SPRING RAIL-JOINT.

At the same meeting, Dr. Robert Grimshaw also described a spring rail-joint, the invention of Prof. Dr. Köpcke, of Dresden.

The invention is designed to give both vertical and lateral stiffness to the joint, while permitting lengthwise expansion of the rails. To make it in an ordinary T-rail, two lengthwise saw-kerfs are made in the web for about one foot at each end separating the web from the head and the flange respectively. The head is then entirely removed by a cross cut for about the same length, the web bent inwards at right angles and the flange bent downwards, also at right angles. These bent portions may then be united to corresponding portions of a similarly-treated rail, by bolts or rivets; suitably spaced holes having been punched before the bending. A fish-plate may be used on the outside of the rails if desired.

PROSPECTIVE INCREASE IN THE CONSUMPTION OF IRON.

In an article recently published in the *Engineering Magazine*, Mr. Edward Atkinson ventures the prediction that from the present time until 1900, the consumption of iron in this country may be expeeted to increase, not only in the present ratio to the increase of population, but also in an accumulated ratio corresponding to the increase *per capita*, which was developed between 1877 and 1889. Assuming, as he does, that the consumption *per capita* will rise only from 300 to 400 pounds, "then the 80,000,000 people who will occupy this country in the year 1900 may require, in addition to our present supply, not less than 7,000,000 gross tons.

Making the assumption that the demand of Great Britain, France Germany, and Belgium shall increase only twenty per cent., that increase will create a demand in 1900 for 2,000,000 tons in addition to their present con-

sumption. If the consumption of the rest of Europe, of Asia, of Africa, of South and Central America and of Australia shall increase from eleven or twelve pounds *per capita* to twenty-two or twenty-four pounds, this, in addition to their present supply of 60,000,000 tons, will require 6,000,000 tons more.

He, thereupon, summarizes the results of these prospective increases in the demand for iron, showing, on the basis of his assumptions, that the world's prospective demand for iron in 1900 will be not less than 40,000,000 tons.

W.

TIN-PLATE PRODUCTION IN THE UNITED STATES.

The report of special agent Ira Ayer, of the Treasury Department, on the condition of the tin-plate business in the United States, exhibits a substantial growth of the industry. During the fiscal year ended June 30, 1895, the production in the United States of commercial tin- and terne-plates was 193,801,073 pounds, against 139,223,467 pounds during the previous fiscal year, showing an increased production of 39 per cent. Of the production for the year, 160,576,934 pounds, or about 83 per cent., were made from sheets rolled in the United States, against about 62 per cent. for the fiscal year ended June 30, 1894. The quantity of sheets of American manufacture used during the last fiscal year was 31,253,467 pounds in excess of the entire production of commercial tin- and terne-plates during the fiscal year ended June 30, 1894. The production for the year, distributed according to weight and kind of plates, was as follows:

Fiscal Year Ended June 30, 1895.	Lighter than 63 Pounds per 100 Square Feet. Pounds.	63 Pounds per 100 Square Feet and heavier. Pounds.	Total. Pounds.
Tin-plates	103,256,143	17,071,806	120,327,949
Terne-plates	62,934,216	10,538,908	73,473,124
Total	166,190,359	27,610,714	193,801,073

The production of black plates in the United States during the fiscal year, by quarters, was as follows:

Quarters.	Lighter than 63 Pounds per 100 Square Feet. Pounds.	63 Pounds per 100 Square Feet and heavier. Pounds.	Total. Pounds.
1894, September 30	26,681,855	5,570,511	32,252,366
1894, December 31	16,801,660	8,805,543	25,607,203
1895, March 31	37,751,102	11,388,665	49,139,767
1895, June 30	67,229,153	11,342,990	78,572,143
Total	148,463,770	37,107,709	185,571,479

Total production for the fiscal year ended June 30, 1895, 185,571,479 pounds; same, fiscal year ended June 30, 1894, 98,970,880 pounds; increase, 86,600,599 pounds, or 87½ per cent.

The total imports during the fiscal year ended June 30, 1895, were 513,963,401 pounds; total exports for the same period, 126,777,800 pounds; net imports, 387,185,601 pounds; total domestic production, 193,801,073 pounds. Approximate consumption in the United States, 580,986,674 pounds; average annual capacity of mills completed June 30, 1895 (144), say, 450,000,000 pounds; same, of mills completed and in course of construction, June 30, 1895, say, 570,000,000 pounds.

From Colonel Ayer's previous reports, and from the foregoing abstract the editor of the *Bulletin* of the American Iron and Steel Association has compiled the following table of the production of tin-plates and terne-plates in the United States, from July 1, 1891, when the tin-plate duty of the McKinley tariff went into effect, until June 30, 1895, or exactly four fiscal years:

Fiscal Years.	Tin-Plates. Pounds.	Terne-Plates. Pounds.	Total. Pounds.
1892	4,539,590	9,107,129	13,646,719
1893	45,743,107	54,076,095	99,819,202
1894	81,609,765	57,613,702	139,223,467
1895	120,327,949	73,473,124	193,801,073

TECHNICAL NOTES.

Apropos to the approaching completion of the trans-Siberian railway, to the accomplishment of which the Russian Government is directing all its energies, it is suggested that it might be found desirable to extend the American system of railways northwardly to Alaska, to a terminus at Behring Strait, on the Pacific, by which connection could be established, through a system of train ferriage across the Strait, between the American and Asiatic-European railway systems. This connection, if realised, would make possible a *continuous journey by rail between Paris and New York.*

Metallic lactates are strongly commended to electroplaters by Dr. Jordis, in a communication made to the German Electro-Chemical Society. He affirms that lactic acid affords an excellent solvent in electroplating baths, and yields good, adherent metallic deposits. He reports that he has succeeded in obtaining from lactate baths, coatings of copper and brass, of varying shades, on iron, zinc and copper; of zinc on iron and copper; and of iron on nickel. Silver lactate yields a pure white coating of silver on amalgamated brass, which takes a high polish.

An ingenious method for the *illumination of opaque objects* for examination under the microscope, and which is said to be applicable to even the strongest magnifications, has been devised by Mr. Charles Fremont, and

is described and illustrated in the *Scientific American*, of October 12, 1895. Mr. Fremont's method consists, briefly, in effecting the illumination through the interior of the tube of the microscope, and of the objective, by means of an adjustable concave mirror, and a prism suitably arranged within the tube, and which receive the light from an exterior source through an aperture in the side of the microscope tube, and direct it vertically upon the object under examination. The concave mirror and prism are provided espectively, with an opening through which a conical tube passes inside of, and in the vertical axis of, the microscope tube, and which permits the object to be viewed without interference from the admitted light. The arrangement is pronounced to be much superior to other artifices heretofore employed for the same purpose. W.

BOOK NOTICES.

Engineering Contracts and Specifications, including a Brief Synopsis of the Law of Contracts and Illustrative Examples of the General and Technical Clauses of Various Kinds of Engineering Specifications. Designed for the use of Students, Engineers and Contractors. By J. B. Johnson, C.E., Professor of Civil Engineering, Washington University, St. Louis, Mo., etc. First edition. Engineering News Publishing Company, New York. 1895. Price, $4.00.

It has too long been the reproach of our schools of engineering that the training which they give their pupils is too largely theoretical, and especially, that the business side of engineering is too little taken into account, so that the graduates proved to be in too many cases highly educated young gentlemen, quite incapable of doing anything in particular until they had unlearned most of what they had acquired.

Professor Johnson, himself a most able instructor, and yet pre-eminently a practical man, whose recent work on the "Theory and Practice of Modern Framed Structures" is now the standard work on that subject, goes a long way, in the present volume, to remove this reproach by making the student acquainted, as well as can be done by the printed page, with what may be called engineering business.

The work differs from that of Professor Haupt, which has been before the public for a number of years, chiefly in discussing at considerable length the law of contracts.

Although the author disclaims any intention of supplanting the professional lawyer, he nevertheless avows his object of rendering it in many cases unnecessary to call in the services of that functionary, by pointing out to the engineer the legal pitfalls which he may avoid.

Nearly 300 pages are occupied by well-chosen examples of modern specifications by prominent engineers, whose names are given, and not only the student but the practicing engineer will find it well worth while to study carefully the author's discussion of contracts and specifications. T.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, November 20, 1895.*]

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, November 20, 1895.

JOS. M. WILSON, President, in the chair.

Present, 195 members and visitors.

Additions to membership since last report, 15.

Dr. Robert Grimshaw described, with the aid of lantern pictures, a number of "Machine Shop Wrinkles," consisting of novel and ingenious tools, mechanical artifices and expedients, etc., used in notable machine shops, and which had fallen under his observation in various places.

Mr. Patrick B. Delany, of New York, described and gave an exhibition of the operation of his system of machine telegraphy. The invention involves a system of mechanical transmission and electro-chemical reception of messages, and is capable of being operated at surprisingly high speeds. Mr. Delany dealt with the proposition of substituting the telegraph for the railways as a means of conveying correspondence, which would require a great enlargement of telegraphic facilities and cheapening the cost of transmission. The speaker gave a brief historical review of past and present systems, and of the growth of telegraphic communication. His new fast system of telegraphy, the speaker claimed, demonstrated the entire feasibility of practically supplanting a large and important portion of the present mail service by telegraphy.

Mr. Delany's remarks and demonstrations were received by the meeting with cordial approbation. At the close of the discussion which followed, on the motion of Mr. Thos. Shaw, numerously seconded, the thanks of the meeting were voted to Mr. Delany for his interesting and important communication. (Mr. Delany's paper will appear in the *Journal.*)

On motion of the same member, the meeting voted to refer the subject of Mr. Delany's system to the Committee on Science and the Arts for investigation and report.

Under new business, Mr. John Shinn presented and had read by the Secretary, a preamble and resolution setting forth the need of amending the patent law of the United States and the rules of procedure in the Patent Office, and asking for the appointment of a special committee to investigate and report upon the subject. The president held that the proposed investigation did not lie within the province of the Institute, and accordingly pronounced the subject to be out of order.

Adjourned.

WM. H. WAHL, *Secretary.*

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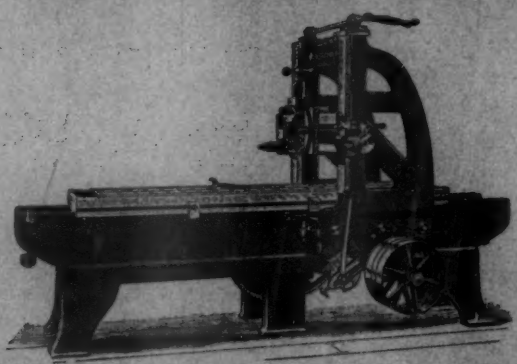

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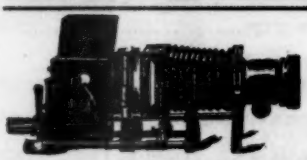

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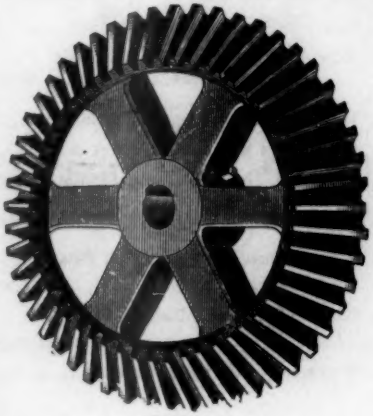

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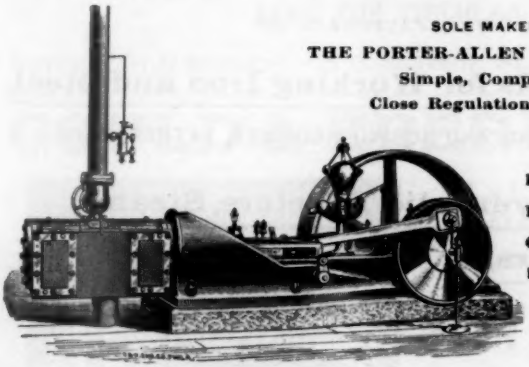

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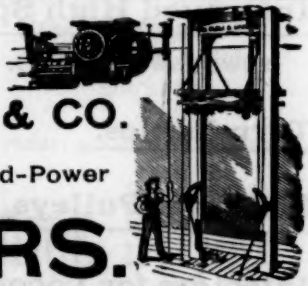

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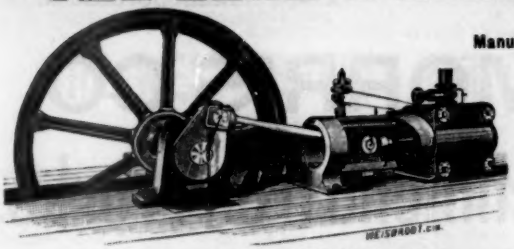

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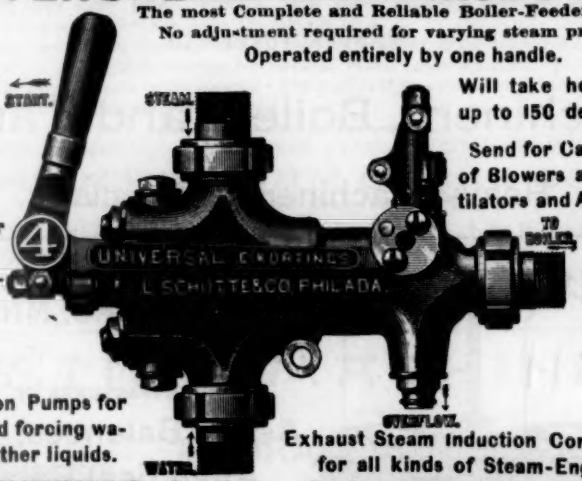

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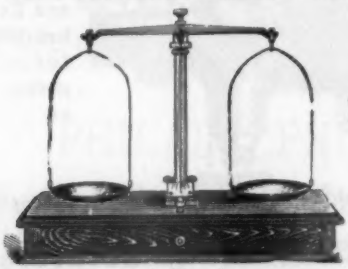

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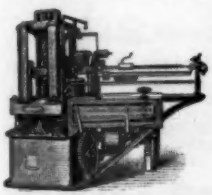

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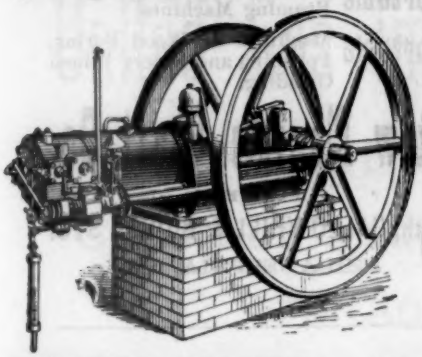

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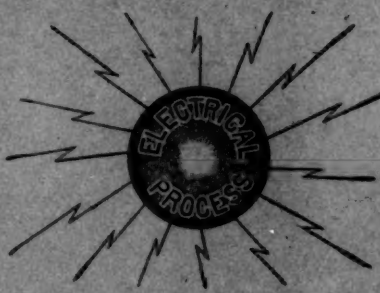

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DIAMETER.	TOOL STEEL. TEMPERED.		DIAMETER.	TOOL STEEL. TEMPERED.	DIAMETER.	TOOL STEEL. TEMPERED.
¼ inch.	$2.00	Bicycle Sizes.	⅞ inch.	$5.75	1¼ inch.	$24.00
5/16 "	2.00		1 "	6.50	1⅜ "	30.00
⅜ "	2.00		1⅛ "	8.00	1½ "	36.00
7/16 "	2.40		1¼ "	10.00	1⅝ "	44.00
½ "	3.00		1⅜ "	12.00	1¾ "	52.00
9/16 "	3.75		1½ "	14.00	1⅞ "	65.00
⅝ "	4.25		1⅝ "	16.00	1⅞ "	80.00
¾ "	5.00		1 "	19.00	2 "	100.00

Discount Governed by Quantity Purchased.

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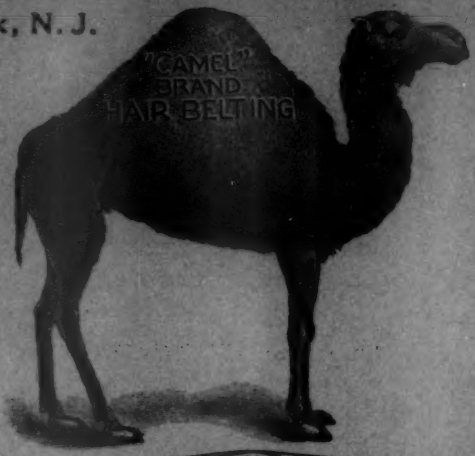

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